A TOPOLOGICAL APPROACH TO FAULT ISOLATION

by

James Dewey Courville

United States
Naval Postgraduate School

THESIS

A TOPOLOGICAL APPROACH

TO

FAULT ISOLATION

by

James Dewey Courville

June 1969

A Topological Approach
to
Fault Isolation

by

James Dewey Courville
Lieutenant (junior grade), United States Navy
B.E.E., Auburn University, 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1969

ABSTRACT

A method is developed for determining by simple external measurements faulty components of passive networks without mutual inductances. A program has been written using topological relationships to calculate the necessary fault isolation reference data. Computation time and storage requirements have been maintained at a minimum.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The author wishes to thank Professor Shu-Gar Chan for his guidance during the period of research and the preparation of this thesis.

I. INTRODUCTION

Locating faulty components of electronic systems is a time consuming process which is very dependent upon the skill and experience of technicians. If the process could be accomplished by means of a digital computer, these disadvantages would be eliminated. As the first step toward achieving this ultimate goal, a computer program for locating network malfunctions of passive networks without mutual inductances has been written in Fortran IV language and is included in Appendix I. For the sake of completeness, the IBM supplied factoring subroutined called by the program is given in Appendix II.

Fault isolation reference data as determined by the program for two example networks is also given in Appendix I. This data is used in section V to demonstrate how faulty components can be located without having to enter the networks.

II. ISOLATING NETWORK MALFUNCTIONS

A. PURPOSE

Whenever a network fails to perform as intended, considerable expenditure of effort on the part of technicians is normally required to isolate the faulty components and take proper corrective procedures. The usual method employed is for the technician to enter the network and take measurements in a particular sequence at predetermined test points. From these measurements an intelligent guess can be made as to which component or module of the network is faulty. If the network still does not perform satisfactorily after replacing these components, the procedure is repeated. Thus, the entire method is time consuming and dependent upon the experience and ability of the technician. In some cases, such as in an integrated circuit, entering the network is not feasible, and the method cannot be employed.

These difficulties could be surmounted if the tests could be made without entering the network and if a computer could be used to analyze the data obtained from the measurements. From the analysis of this data, the faulty components could be identified and corrective procedures could then be initiated. Some studies of performing fault isolation on various types of networks in this manner have been undertaken [1 - 7], but success has been limited. The scope of the problem was, therefore, limited in this study to passive networks without mutual inductances.

B. BASIS FOR PROPOSED METHOD

It is well known that any network of the type being considered can be externally characterized in terms of Z-parameters.

Consider the following two-port network with the input and output variables as indicated.

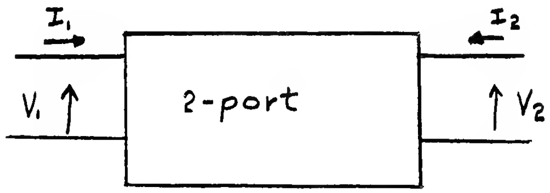


Fig. 2-1
2-port network

The equations of the voltages as linear functions of the currents in matrix form is as follows

$$\begin{vmatrix} V_1 \\ V_2 \end{vmatrix} \quad \begin{vmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{vmatrix} \quad \begin{vmatrix} I_1 \\ I_2 \end{vmatrix} \tag{2-2-1}$$

The forward voltage ratio transfer function, U_{12}, is defined as the ratio of the output voltage to the input voltage with the output current set equal to zero. Similarly, the reverse voltage ratio transfer function, U_{21}, is defined as the ratio of the input voltage to the output voltage with the input current set equal to zero. Applying these definitions to equation (2-2-1) and solving for U_{12} and U_{21} yields the following.

$$U_{12} = \frac{z_{21}}{z_{11}} \tag{2-2-2}$$

$$U_{21} = \frac{z_{12}}{z_{22}} \tag{2-2-3}$$

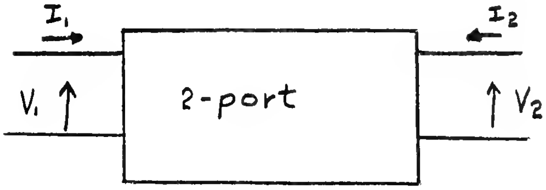
From equations (2-2-2) and (2-2-3) it can be seen that a change in any one of the Z-parameters will cause a change in one or possibly both of the voltage ratio transfer functions, depending on whether or not the Z-parameters are independent. Since the Z-parameters depend upon the values of the components of the network, any change in a component will cause a change in the voltage ratio transfer functions. It is this fact which is the basis of the proposed method of isolating network malfunctions.

C. PROPOSED METHOD

Since each point on the curves of the voltage ratio transfer functions versus frequency is dependent upon the values of the network components, the behavior of these gain curves could be predetermined at any particular frequency by varing the network components about their nominal values and then solving equations (2-2-2) and (2-2-3). The behavior of the curves at several test frequencies could then be coded and stored as fault isolation reference data. The measured values of the voltage ratio transfer functions at the test frequencies could then be entered in the computer, and the computer could sort the fault isolation reference data to determine values for the components of the network. Any change in the components from their nominal value is thus determined.

Such a method of determining network component values from measurements of the voltage ratio transfer functions is dependent upon some scheme of choosing test frequencies at which to make the measurements. The number of test frequencies chosen is limited by excessive storage requirements at one extreme and by inadequate information at the other extreme.

Consider the following two-port network with the input and output variables as indicated.



<u>Fig. 2-1</u>
2-port network

The equations of the voltages as linear functions of the currents in matrix form is as follows

$$\begin{vmatrix} V_1 \\ V_2 \end{vmatrix} \begin{vmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{vmatrix} \begin{vmatrix} I_1 \\ I_2 \end{vmatrix} \qquad (2\text{-}2\text{-}1)$$

The forward voltage ratio transfer function, U_{12}, is defined as the ratio of the output voltage to the input voltage with the output current set equal to zero. Similarly, the reverse voltage ratio transfer function, U_{21}, is defined as the ratio of the input voltage to the output voltage with the input current set equal to zero. Applying these definitions to equation (2-2-1) and solving for U_{12} and U_{21} yields the following.

$$U_{12} = \frac{z_{21}}{z_{11}} \qquad (2\text{-}2\text{-}2)$$

$$U_{21} = \frac{z_{12}}{z_{22}} \qquad (2\text{-}2\text{-}3)$$

From equations (2-2-2) and (2-2-3) it can be seen that a change in any one of the Z-parameters will cause a change in one or possibly both of the voltage ratio transfer functions, depending on whether or not the Z-parameters are independent. Since the Z-parameters depend upon the values of the components of the network, any change in a component will cause a change in the voltage ratio transfer functions. It is this fact which is the basis of the proposed method of isolating network malfunctions.

C. PROPOSED METHOD

Since each point on the curves of the voltage ratio transfer functions versus frequency is dependent upon the values of the network components, the behavior of these gain curves could be predetermined at any particular frequency by varing the network components about their nominal values and then solving equations (2-2-2) and (2-2-3). The behavior of the curves at several test frequencies could then be coded and stored as fault isolation reference data. The measured values of the voltage ratio transfer functions at the test frequencies could then be entered in the computer, and the computer could sort the fault isolation reference data to determine values for the components of the network. Any change in the components from their nominal value is thus determined.

Such a method of determining network component values from measurements of the voltage ratio transfer functions is dependent upon some scheme of choosing test frequencies at which to make the measurements. The number of test frequencies chosen is limited by excessive storage requirements at one extreme and by inadequate information at the other extreme.

D. DETERMINING THE TEST FREQUENCIES

An intuitively appealing solution to the problem of choosing test frequencies is obtained from an examination of the gain curves of the network. Depending on the purpose of the network, there will be some maximum and some minimum frequency of interest. Since these two frequencies are the extremes of the problem, they should be chosen as test frequencies. Furthermore, the points of inflection of the gain curves should also be chosen as test frequencies, since any change which may occur in the curves is more noticeable at these points. Finally, points midway between the points of inflection of the curves should be chosen as test frequencies in order to insure that adequate information is provided.

The maximum and minimum frequencies of interest can be determined by factoring the nominal voltage ratio transfer functions. These factors, poles and zeroes, are related to the cutoff frequencies of the network. The magnitude of the pole or zero having the largest magnitude is thus a good approximation of the largest frequency of interest. Taking twice this magnitude as the largest test frequency will provide sufficient information about the behavior of the curve beyond the last cut-off frequency. Normally, the minimum test frequency should be zero, since this provides DC gain information, and since measurements at this point are easy.

E. SUMMARY OF PROPOSED METHOD

The entire procedure is summarized below.

(1) Determine the voltage ratio transfer functions, $U_{12}(s)$ and $U_{21}(s)$, as functions of complex frequency for nominal network component values.

(2) Factor the voltage ratio transfer functions, and determine the magnitude of the factor having the largest magnitude. Take twice this magnitude as a test frequency.

(3) Scan the gain curves from this frequency to zero frequency, and choose as test frequencies those frequencies at which the slope of the curves becomes zero or change from zero. Also choose as test frequencies the midpoint between adjacent test frequencies thus far chosen. As the final test frequency choose zero.

(4) Store the magnitude of the gain curves at each of the test frequencies.

(5) Vary the network component values about their nominal values, and evaluate the gain curves at the test frequencies for each variation. Store the variation in the gains at the test frequencies from the nominal value along with the variation of the component values from their nominal value. This data may be stored in coded form so as to reduce storage requirements.

Given measured values of the gains of the network at each of the test frequencies, the data now in storage can be sorted, and the variation of the components from their nominal values can be read out. From this output data, the network malfunction can be isolated.

Due to the large number of times the gains must be evaluated, some method of rapidly determining the voltage transfer ratios of the network is mandatory if the preceding method is to be feasible. It is for this reason that topological formulas were used for determining the network functions.

III. TOPOLOGICAL FORMULAS

A. GENERAL

It has been shown in recent years that topological formulas for computing network functions of passive networks without mutual inductances are rapidly solved on a digital computer [8 - 14]. The principal reason for this rapidity is the elimination of unnecessary calculations resulting from the cancellation of terms.

The following definitions are essential to understanding the topological formulas used in this study for the determination of network functions.

Node	-	a point.
Edge	-	a line segment connecting two nodes.
Graph	-	a finite set of edges and nodes such that no two edges have any points in common other than nodes.
Subgraph	-	a subset of edges and nodes of a graph.
Path	-	a set of edges connecting any two nodes.
Connected graph	-	a graph such that at least one path exists between any two nodes of the graph.
Circuit or loop	-	a subgraph such that each node has a path to itself.
Tree	-	a circuitless and connected subgraph containing all the nodes of a connected graph.
2-tree	-	each of a pair of unconnected and circuitless subgraphs formed by removing any one edge of a tree.

3-tree	-	each of three unconnected and circuitless subgraphs formed by removing any one edge of a 2-tree.
Incidence matrix, A_a	-	a matrix whose elements are defined as follows:

$a_{ij} = 1$ if the edge "j" is incident at node "i."

$a_{ij} = 0$ if the edge "j" is not incident at node "i."

A	-	incidence matrix with any one dependent row deleted.
$Y_e(s)$	-	the Laplace transform of the element admittance matrix of the network "N" in square form.

B. TOPOLOGICAL NETWORK FUNCTIONS

There are several sources available in which the derivation in topological form of network functions for passive networks without mutual inductances is discussed [8 - 16]. The results of these studies applicable to voltage transfer functions are presented in this section.

Consider the following two-port network with the external terminals and variables defined as indicated.

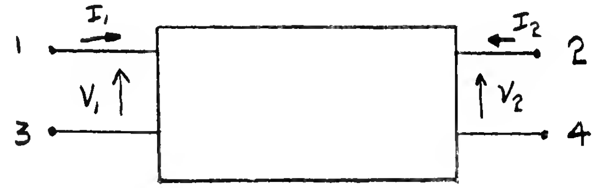


Fig. 3-1
2-port network with external terminals numbered.

The voltage ratio transfer function, U_{12}, is defined as the ratio of the output voltage to the input voltage with the output current set equal to zero.

$$U_{12} = \left. \frac{V_2}{V_1} \right|_{I_2=0} \tag{3-2-1}$$

The inverse voltage ratio transfer function, U_{21}, is similarly defined.

$$U_{21} = \left. \frac{V_1}{V_2} \right|_{I_1=0} \tag{3-2-2}$$

Defining W_{ij} as the sum of the tree admittance products of a network formed by shorting node "i" of network "N" to node "j" and A_i as the incidence matrix of this modified network, the following equations can be derived from topological relationships.

$$U_{12} = \frac{\frac{1}{2}\left(W_{14} + W_{23} - W_{12} - W_{34} \right)}{W_{13}} \tag{3-2-3}$$

$$U_{21} = \frac{\frac{1}{2}\left(W_{14} + W_{23} - W_{12} - W_{34} \right)}{W_{24}} \tag{3-2-4}$$

$$W_{ij} = \left| A_i Y_e(s) A_i^T \right| \tag{3-2-5}$$

The use of these formulas is illustrated in Example 3.1. Example 3.1. Determine the voltage ratio transfer functions using topological formulas for the following network.

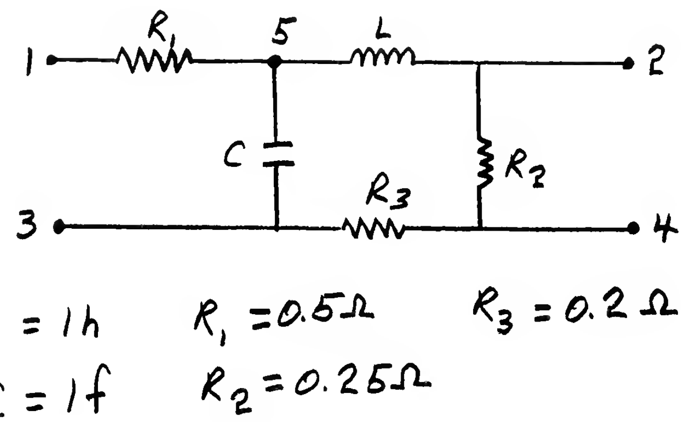


Fig. 3-2
Example 2-port network

The modified network resulting from shorting nodes 1 and 3 is shown below.

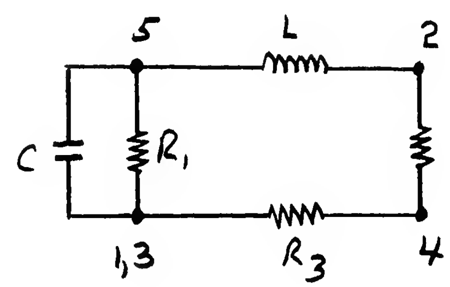


Fig. 3-3
Network resulting when nodes 1 and 3 are shorted.

The trees of this modified network are given in Fig. 3-4.

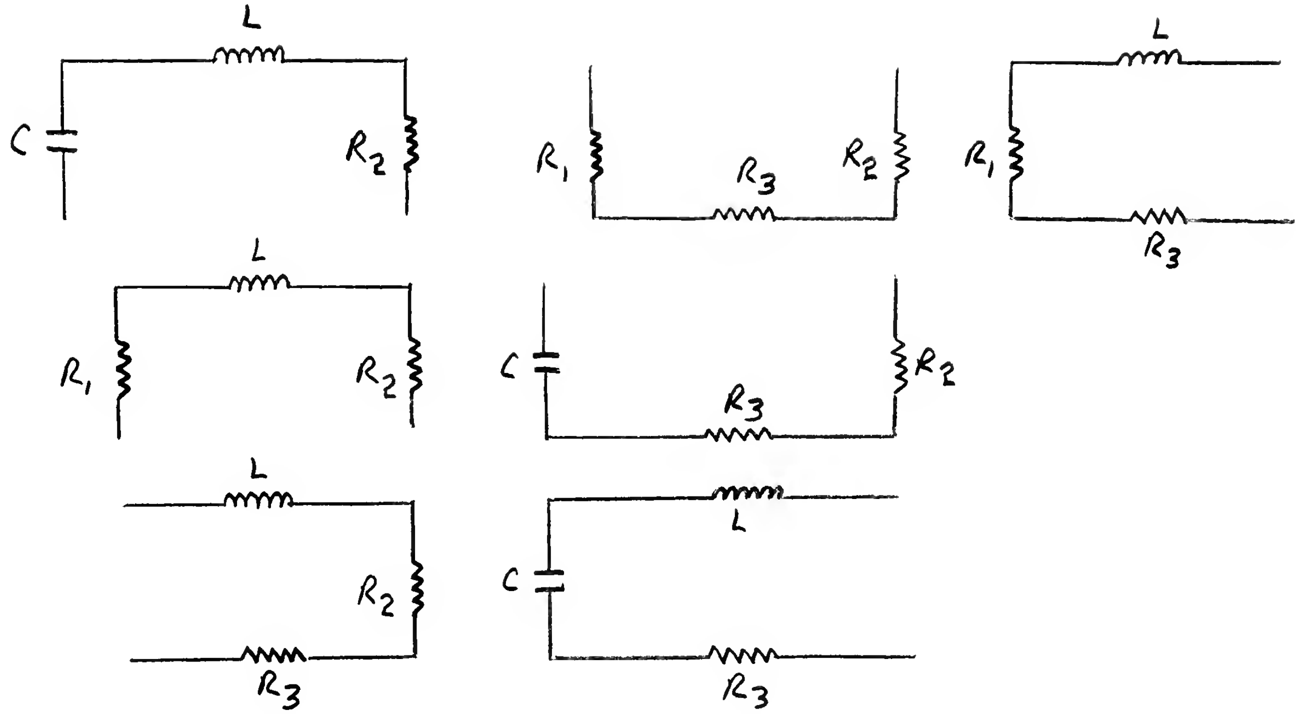


Fig. 3-4
Trees of network in Fig. 3-3.

Applying the definition of W_{ij} yields the following.

$$W_{13} = [(s)(1/s)(4)] + [(2)(1/s)(4)] + [(1/s)(4)(5)] + [(2)(5)(4)] + [(s)(5)(4)] + [(1/s)(s)(5)] + [(1/s)(2)(5)]$$

$$= 49 + 38/s + 20s$$

The modified network resulting from shorting nodes 1 and 2 is shown below.

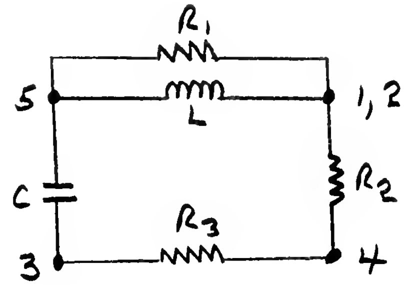


Fig. 3-5
Network resulting when nodes 1 and 2 are shorted.

This modified network has the following trees.

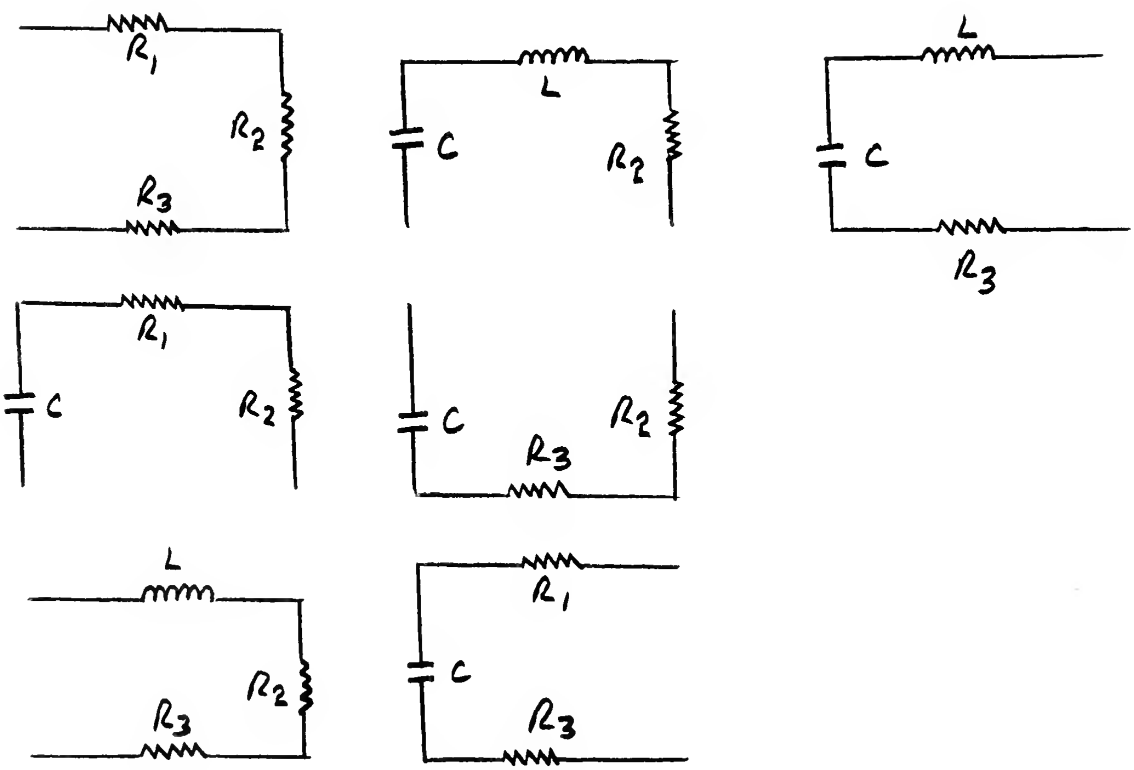


Fig. 3-6
Trees of network in Fig. 3-5.

Summing the admittance products of these trees yields W_{12}.

$$W_{12} = [(2)(4)(5)] + [(s)(2)(5)] + [(1/s)(4)(5)] + [(s)(1/s)(4)] + [(s)(5)(4)] + [(2)(s)(5)] + [(1/s)(s)(5)]$$

$$= 49 + 20/s + 38s$$

The modified network resulting from shorting nodes 2 and 4 is given in Fig. 3-7.

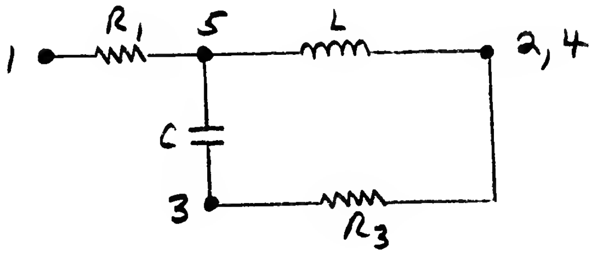


Fig. 3-7
Network resulting when nodes 2 and 4 are shorted.

This modified network has the trees given below.

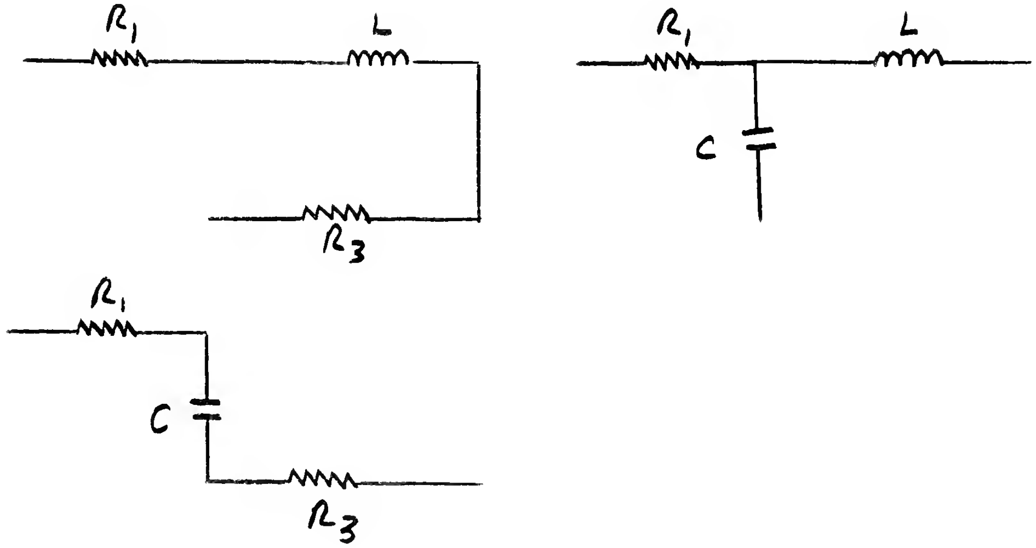


Fig. 3-8
Trees of network in Fig. 3-7.

Summing the admittance products of these trees yields W_{24}.

$$W_{24} = [(1/s)(5)(2)] + [(1/s)(5)(2)] + [(s)(5)(2)]$$

$$= 2 + 10/s + 10s$$

The modified network resulting from shorting nodes 1 and 4 is given in Fig. 3-9.

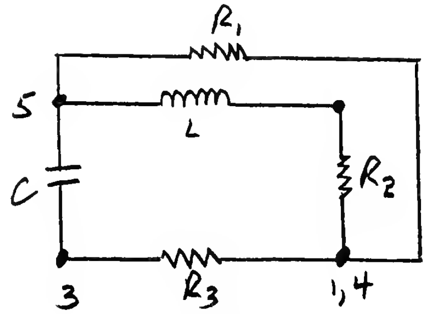


Fig. 3-9
Network resulting when nodes 1 and 4 are shorted.

This modified network has the following trees.

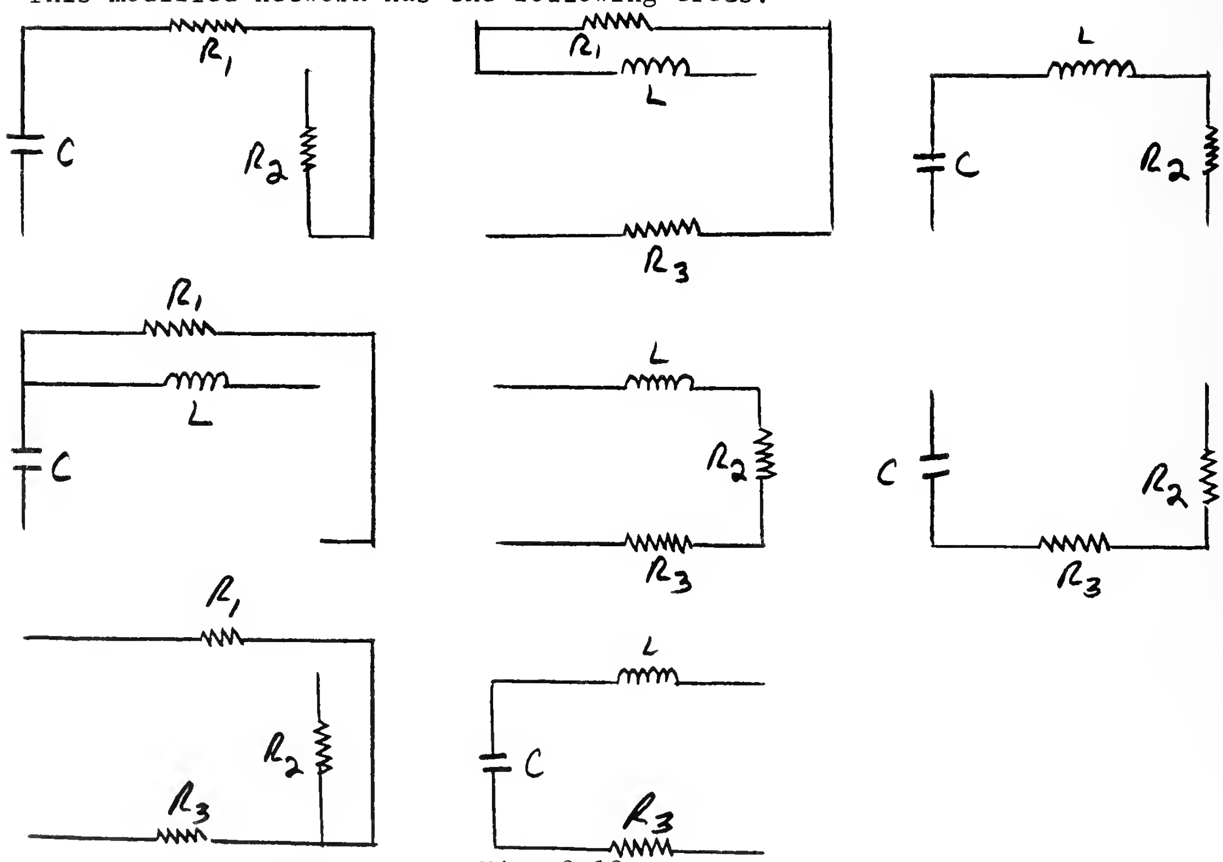


Fig. 3-10
Trees of network in Fig. 3-9.

Summing the admittance products of these trees yields W_{14}.

$$W_{14} = [(1/s)(4)(5)] + [(s)(1/s)(5)] + [(s)(4)(5)]$$
$$+ [(2)(1/s)(5)] + [(2)(4)(5)] + [(1/s)(4)(s)]$$
$$+ [(2)(1/s)(s)] + [(2)(4)(s)]$$
$$= 51 + 30/s + 28s$$

The modified network which results when nodes 2 and 3 are shorted is given below.

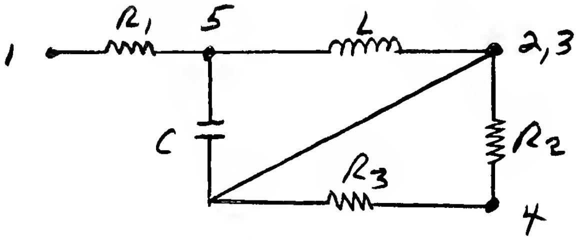


Fig. 3-11
Network resulting when nodes 2 and 3 are shorted.

This modified network has the following trees.

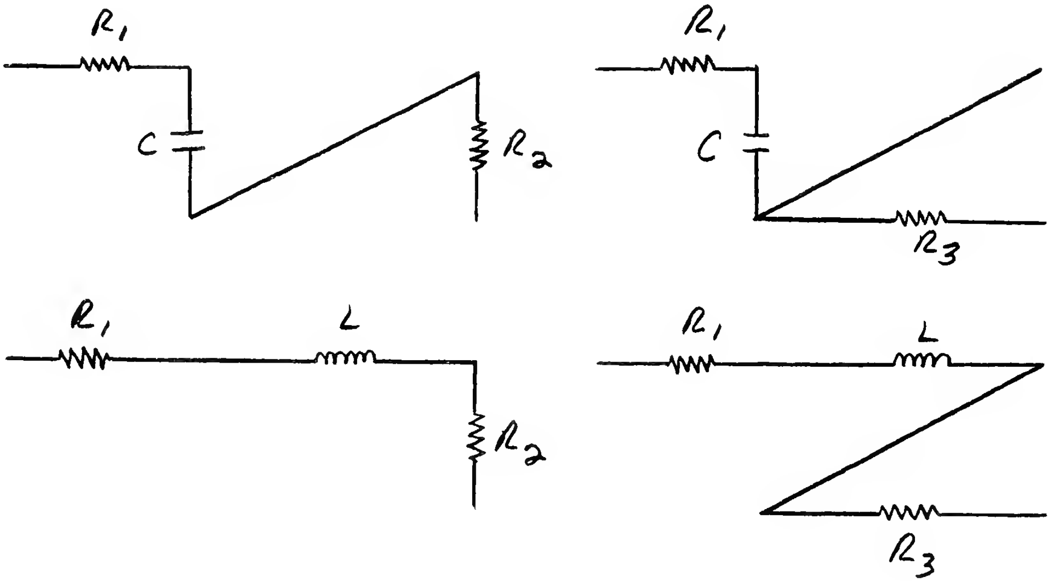


Fig. 3-12
Trees of network in Fig. 3-11.

Applying the definition of W_{ij} yields the following for W_{23}.

$$W_{23} = [(s)(4)(2)] + [(s)(5)(2)] + [(\tfrac{1}{s})(4)(2)] + [(\tfrac{1}{s})(5)(2)]$$

$$= 18/s + 18s$$

The modified network which results when nodes 3 and 4 are shorted is as follows:

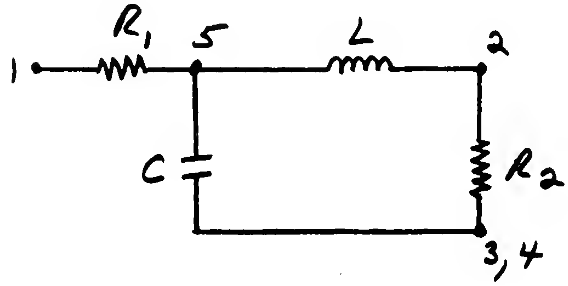


Fig. 3-13
Network resulting when nodes 3 and 4 are shorted.

This modified network has the following trees.

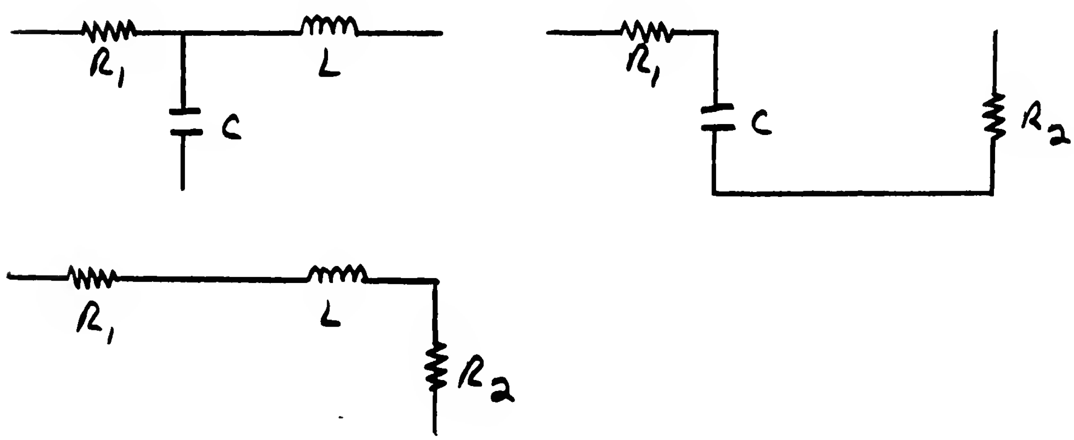


Fig. 3-14
Trees of network in Fig. 3-13.

Summing the admittance products of these trees yields W_{34}.

$$W_{34} = [(\tfrac{1}{s})(4)(2)] + [(s)(4)(2)] + [(s)(\tfrac{1}{s})(2)]$$

$$= 2 + 8/s + 8s$$

Substituting into equation (3-2-3) yields the following.

$$U_{12} = \frac{\tfrac{1}{2}\left([51 + 30/s + 28s] + [18/s + 18s] - [49 + 20/s + 38s] - [2 + 8/s + 8s]\right)}{49 + 38/s + 20s}$$

$$= \frac{10}{20s^2 + 49s + 38}$$

Similarly, substituting into equation (3-2-4) yields U_{21}.

$$U_{21} = \frac{5}{5s^2 + 5 + 5}$$

Although the calculations involved in Example 3.1 are simple and straight forward, it is apparent that some method of systematically determining the trees of a network is necessary. Several methods of finding all the trees of a network have been developed [17 - 25] but were not suitable for this study due to eigher long computation time, large memory requirements, formation of circuits which must be eliminated, or combinations of these disadvantages. The method which was used was presented by Wen-Tao Chang in a thesis to the Naval Postgraduate School [8].

C. DICHOTOMY TREE FINDING METHOD

The dichotomy method for determining all the trees of a graph is presented in the following algorithm.

(1) List the set whose subsets are the elements connected to each node of the graph, and call it the node set.

(2) Compare the first subset of the node set with any one of the other subsets which contains at least one element in common. Store this intersection of the two subsets as an element of a set called the common set. Form two new node sets in the following manner.

(a) Eliminate the elements which the two subsets of the node set had in common from both of the subsets, and place this new node set in a new column.

(b) Except for forming a new column, repeat the procedure in (a), remove the second subset, and add its remaining elements to the remaining elements of the first subset.

(3) Continue to repeat (2) until a null subset is obtained in each of the new node sets.

(4) Order the common set in the following manner.

(a) Group together the subsets in the first column.

(b) Form other groupings by replacing the subsets of the first column with those of the corresponding rows of the other columns.

(5) All the trees of the graph can now be determined by taking one element at a time from each of the subsets of the groupings in the common set.

Example 3.2. Determine all the trees of the following graph using the dichotomy tree finding method. Use a letter to designate each element of the graph.

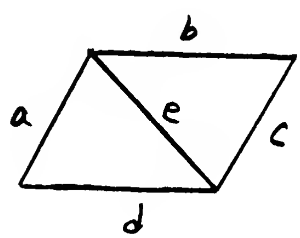


Fig. 3-15
Graph with edges designated by letters.

Solution.

$(\underline{a}d)(\underline{a}be)(bc)(cde)$ $\quad$ $(\underline{d})(be)(bc)(c\underline{d}e)$

a $\quad$ d

$(\underline{b}de)(\underline{b}c)(cde)$ $\quad$ $(de)(c)(cde)$ $\quad$ $(\underline{c}e)(be)(b\underline{c})$ $\quad$ $(\underline{e})(b\underline{e})(b)$

b $\quad$ c $\quad$ e

$(\underline{cd}e)(\underline{cd}e)$ $\quad$ $(\underline{c})(\underline{c})$ $\quad$ $(\underline{b}e)(\underline{b}e)$ $\quad$ $(\underline{b})(\underline{b})$

cde $\quad$ c $\quad$ be $\quad$ b

grouping	trees
a, b, cde	abc, abd, abe
a, de, c	adc, aec
d, c, be	dcb, dce
d, e, b	deb

Thus, all the trees of the graph are determined without duplication.

IV. THE COMPUTER PROGRAM

A computer program for determining the data necessary for locating network malfunctions according to the methods presented in Sections II and III has been written and is included in Appendix I. The section of the program which determines the voltage ratio transfer functions is a modification of a program developed by Wen-Tao Chang [8] for determining network functions.

A. PROGRAM LIMITATIONS

The program is limited to passive networks without mutual inductances. Furthermore, the network must be such that its graph contains from three to fifteen nodes with less than three hundred edges and no more than five parallel elements between any pair of nodes. If necessary, these graph limitations may be increased by altering the dimension statements in the program.

B. RULES FOR LABELING THE GRAPH OF THE NETWORK

The input and output nodes of the network graph are designated by a number from one to three or four, depending upon the ground condition of the network. Two possible configurations are shown in Fig. 4.1.

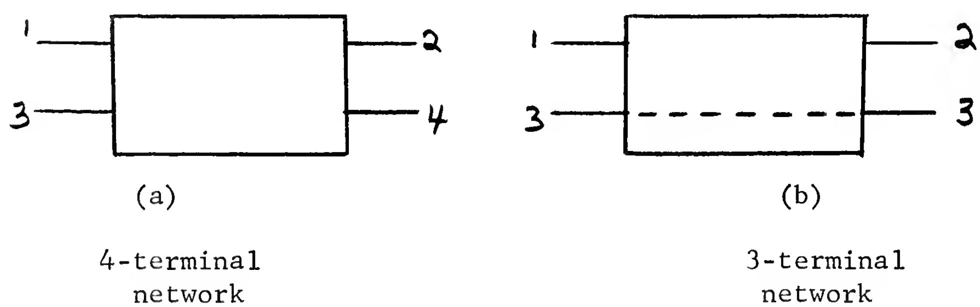


Fig. 4.1
External node designations

The node designations indicated in Fig. 4.1(a) apply to a network having an element which has a finite and non-zero admittance between nodes three and four. This configuration is henceforth called ground condition one. The input and output terminals are designated as indicated in Fig. 4.1(b) if the network has an infinite admittance element between the lower nodes of the input and output terminals. This configuration is henceforth called ground condition two.

The remaining nodes are numbered consecutively from five to the total number of nodes in the graph of the network in the case of ground condition one. If ground condition two is applicable, the remaining nodes of the network graph are numbered consecutively starting with number four. The elements of the network graph may be numbered from one to the total number of elements in the graph with the condition that parallel elements must be numbered consecutively.

For example, consider a two-port network having a graph which satisfies ground condition one and has seven nodes and eight elements. Assume that two of the nodes which are neither output nor input terminals are connected by three parallel elements. The graph would then be labeled as follows:

(1) Label the external terminals in accordance with Fig. 4.1(a).

(2) Label the remaining nodes with numbers from five to seven.

(3) Label the parallel edges with three consecutive numbers between one and eight.

(4) Label the remaining edges with the numbers between one and eight not used in (3).

If the network satisfies ground condition two instead of ground condition one, the graph would then be labeled as follows:

(1) Label the external terminals in accordance with Fig. 4.1(b).

(2) Label the remaining nodes with numbers from four to seven.

(3) Label the parallel edges with three consecutive numbers between one and eight.

(4) Label the remaining edges with the numbers between one and eight not used in (3).

C. INPUT DATA

The format of the input data cards and the information they must contain is presented below.

Card Number	Card Columns	Information Required
1	1-10	Number of nodes.
	11-20	Number of elements.
	21-30	Ground condition.
	31-40	Number two to indicate a two-port network.
	41-80	Disregard.
2	1-10	Number used to label network element.
	11-13	Smaller of the two numbers used to label one of the two nodes connected by the preceding element.
	14-16	Larger of the two numbers used to label one of the two nodes connected by the preceding element.
	17-26	Magnitude of the admittance of the preceding element.

Card Number	Card Columns	Information Required
	27-31	Degree in S-domain of the admittance of the preceding element.
	32-80	Disregard.

The remainder of the data cards for the given network have the same format as card number two. Thus, the total number of data cards for any given network is equal to one plus the number of elements. If the program is to determine fault isolation data for more than one network, the data cards for the next network are placed following the data cards for the preceding network. A blank card is placed at the end of the entire data deck.

Table 1 indicates the input data for two networks shown in Fig. 4.2(a) and Fig. 4.2(b).

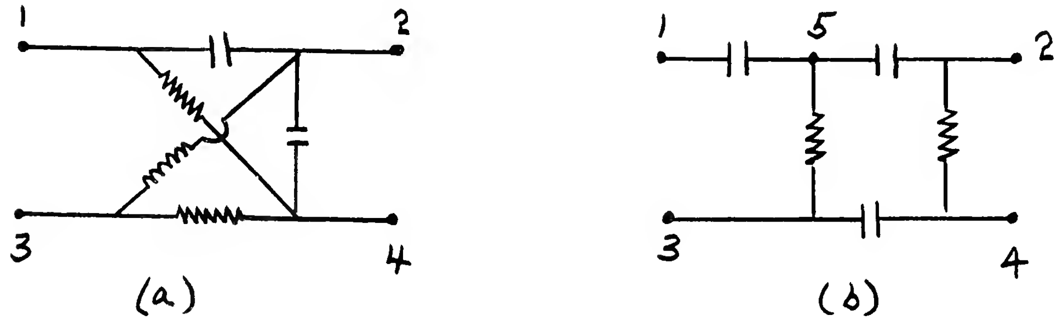


Fig. 4.2
Example 2-port networks

Table 1. Input data for networks of Fig. 4.2

Card Column	1	11	21	31	41
Network (a)	4	5	2	2	
	1	1 2	1.0000	1	
	2	2 3	2.0000	-1	
	3	1 4	1.0000	0	
	4	2 4	1.0000	1	
	5	3 4	1.0000	0	
Network (b)	5	5	2	2	
	1	1 5	1.0000	1	
	2	3 5	0.2500	0	
	3	2 5	2.5000	1	
	4	3 4	2.5000	1	
	5	2 4	0.5000	0	

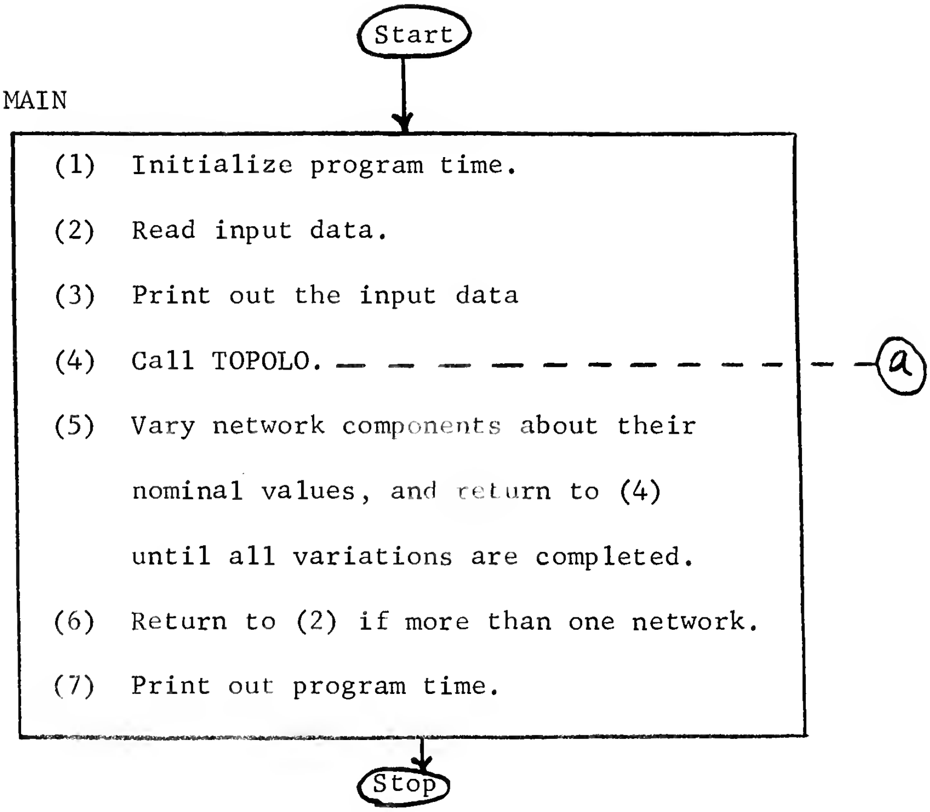
D. PROGRAM OUTPUT

The program output for the network components at their nominal values includes the voltage ratio transfer functions, their poles and zeroes, the test frequencies, and the corresponding magnitudes of the voltage ratio transfer functions at each of these frequencies. Also included as output data is the element which was varied, the percent variation of the element from its nominal value, and the magnitude of the voltage ratio transfer functions at each of the test frequencies when the element is so varied.

E. BLOCK DIAGRAM OF THE PROGRAM

The following is a block diagram of the computer program given in Appendix I.

MAIN


Start
(1) Initialize program time.
(2) Read input data.
(3) Print out the input data
(4) Call TOPOLO.
a
(5) Vary network components about their nominal values, and return to (4) until all variations are completed.
(6) Return to (2) if more than one network.
(7) Print out program time.
Stop

a

TOPOLO

(1) Set constants.

(2) Call MODNET.

(3) Call TREE.

(4) If all W_{ij} have not been determined, return to (1).

(5) Call RESULT. b

(6) Return to (5) in MAIN.

MODNET

(1) Form modified network as indicated by constants set in (1) of TOPOLO.

(2) Return to (3) of TOPOLO.

TREE

(1) Set constants.

(2) Call NPART.

(3) Call XTREE. c

(4) Calculate all W_{ij}.

(5) Return to (4) in TOPOLO.

NPART

(1) Perform all operations of dichotomy tree finding method except actual formation of trees.

(2) Return to (3) of TREE.

(b)

RESULT

(1) Form the numerator and denominator of the network functions in the S-domain.

(2) Cancel any common factors.

(3) Print out the network functions if this is the first time through result. Otherwise, go to (6).

(4) Call POLRT. — (d)

(5) Print out poles and zeroes of network functions.

(6) Call TESFRQ.

(7) Return to (6) in TOPOLO.

TESFRQ

(1) Determine maximum frequency of interest.

(2) Convert to "jw"-domain and determine frequency response.

(3) From frequency response, determine test frequencies.

(4) Determine magnitude (test magnitudes) of network functions at the test frequencies.

(5) Print out test frequencies and corresponding test magnitudes.

(6) Return to (6) in RESULT.

c

XTREE

(1) Determine the trees of the modified network.
(2) Return to (4) of TREE.

d

POLRT

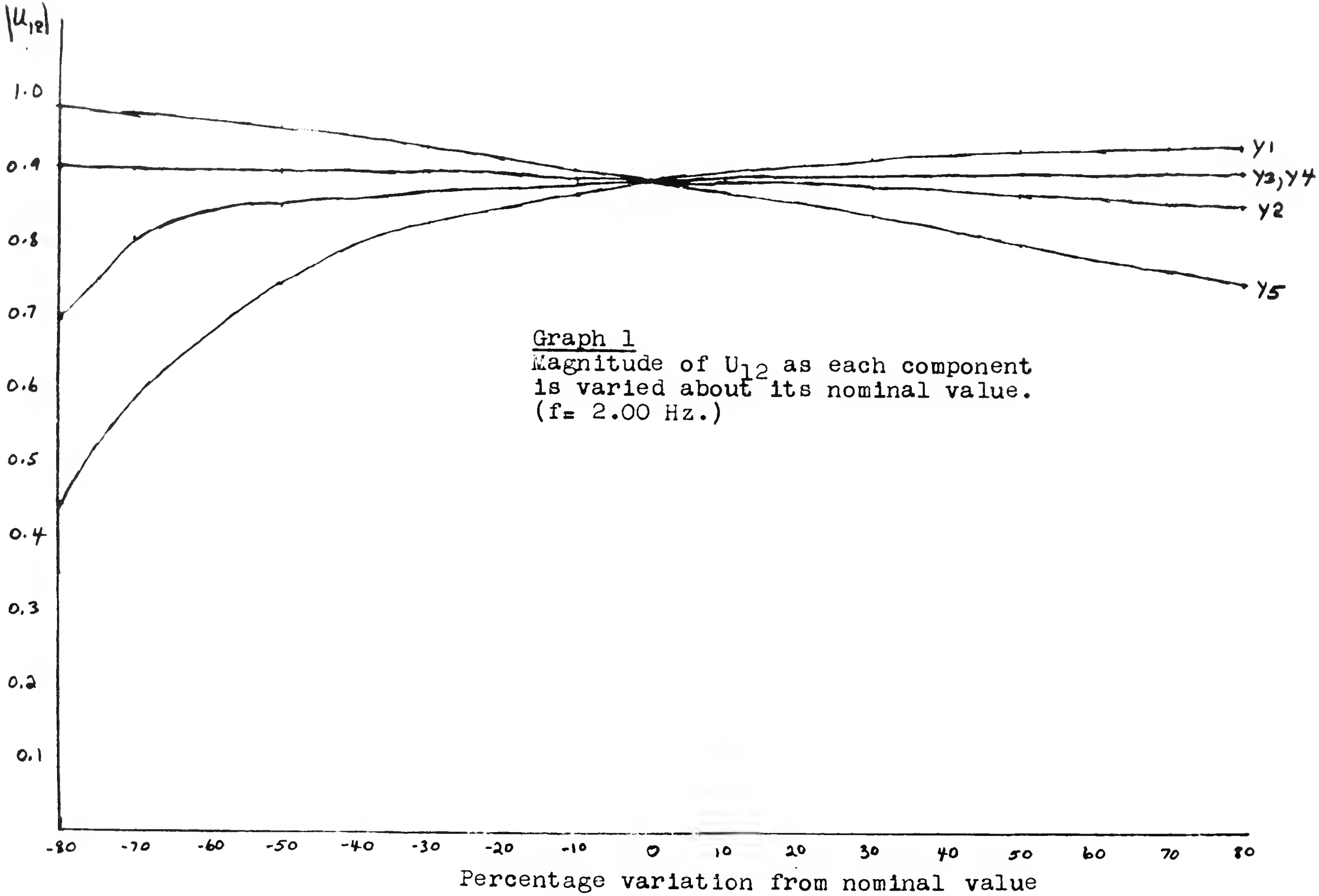
(1) Factor numerator and denominator of network functions.
(2) Return to (5) in RESULT.

E. CONCLUSION

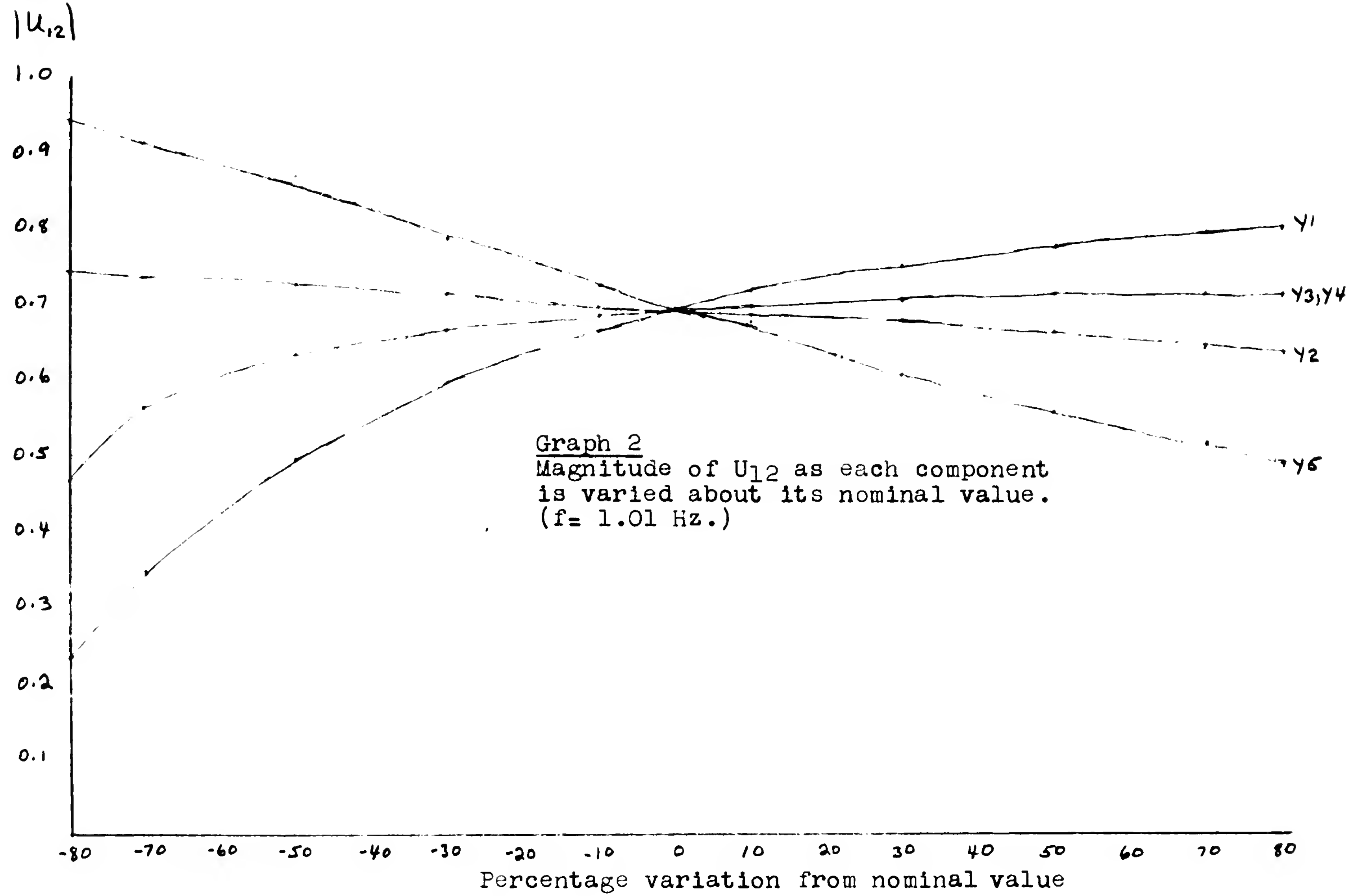
Fault isolation data as determined by the program for two example networks is also given in Appendix I. The networks are given in Fig. 4.2(a) and Fig. 4.2(b), respectively, with nominal component values as indicated in Table 1. From the output data, it can be seen that varying the component values of the networks from their nominal values has produced unique variations in the voltage ratio transfer functions at the test frequencies. These predetermined variations in the voltage ratio transfer functions can now be used as fault isolation reference data.

There are several possibilities as to how this reference data may be used for isolating network malfunctions. One method is to plot the data as was done in Graphs 1 - 3. These plots are a portion of the output data obtained from the program for the network given in Fig. 4.2(b). Only the forward voltage ratio transfer function is considered in the graphs, since this is sufficient information to demonstrate the feasibility of this method.

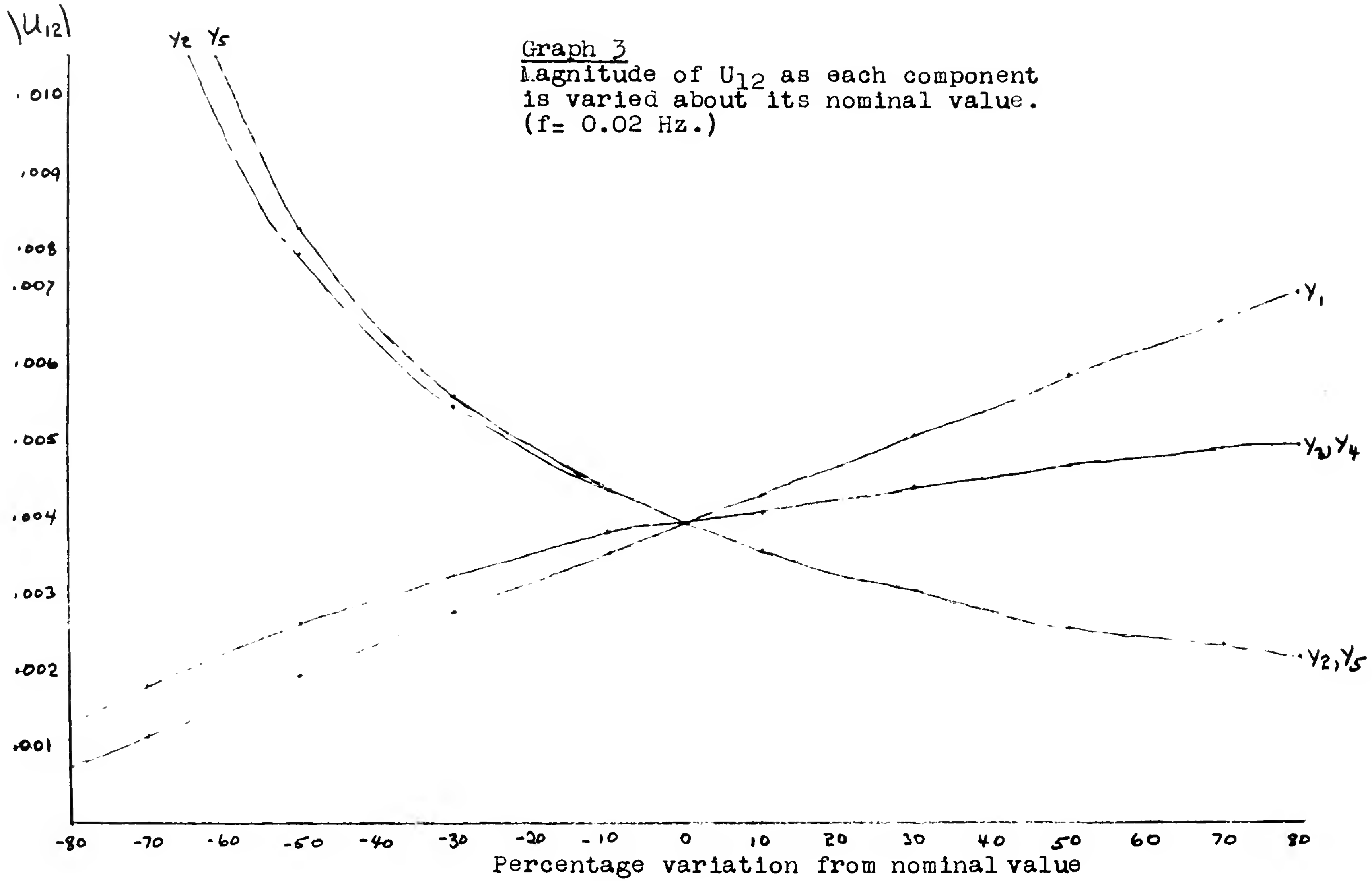
As an example, assume that the network of Fig. 4.2(b) is not performing properly, and it is desired to determine the faulty component. The magnitude of the forward voltage ratio transfer function was measured at each of the predetermined test frequencies, and the following data was obtained.



<u>Graph 1</u>
Magnitude of U_{12} as each component is varied about its nominal value. (f= 2.00 Hz.)



Graph 2
Magnitude of U_{12} as each component is varied about its nominal value. (f= 1.01 Hz.)



Graph 3
Magnitude of U_{12} as each component is varied about its nominal value. (f= 0.02 Hz.)

Test frequency in Hz.	Magnitude
2.00	0.80
1.01	0.56
0.02	0.24×10^{-2}

From Graph 1, the following possibilities are obtained.

(1) Y_1 has decreased 38% from nominal.

(2) Y_3 or Y_4 has decreased 70% from nominal.

(3) Y_5 has increased 46% from nominal.

From Graph 2, the following possibilities are obtained.

(1) Y_1 has decreased 38% from nominal.

(2) Y_3 or Y_4 has decreased 70% from nominal.

(3) Y_5 has increased 50% from nominal.

From Graph 3, the following possibilities are obtained.

(1) Y_1 has decreased 38% from nominal.

(2) Y_3 or Y_4 has decreased 57% from nominal.

(3) Y_2 or Y_5 has increased by 65% from nominal.

The only possibility which is in agreement with all three graphs is (1). It is thus concluded that the faulty component is Y_1 and that it has decreased 38% from its nominal value. Note that only a portion of the program output data was necessary to uniquely identify the faulty component for this example.

From the three graphs, it can be seen that the curves for the elements Y_3 and Y_4 coincide at each of the test frequencies. This can be explained by examining the network shown in Fig. 4.2(b). Note that Y_3 and Y_4 are both capacitors of the same admittance and can both be replaced with a single capacitor of twice the admittance of either one. Thus, the voltage ratio transfer functions are sensitive to the sum of the admittances of Y_3 and Y_4. Since the sum is affected in the same manner by varying either Y_3 or Y_4, the curves of these two components will coincide on all of the graphs.

Instead of having to search through all of the graphs in order to be able to isolate network malfunctions, it is possible that the entire procedure could be accomplished on a computer. The computer could calculate the data contained in the graphs by means of linear interpolation. The measured values of the magnitude of the voltage ratio transfer functions at each test frequency could then be supplied to the computer as additional input data. From this data, the computer could determine the faulty component by sorting the data it has in storage. This method would be considerably faster than the graphical method. The graphical method, however, provides some insight as to the sensitivity of the network to component variations.

The program in Appendix I is sufficiently generalized that it could also be used to determine root locus, frequency response, Z-parameters, Y-parameters, and current ratio transfer functions of passive networks without mutual inductances. The program is also organized in such a manner that with only slight modification situations where more than one component of a network vary simultaneously could be identified for fault isolation purposes. This would greatly enhance the fault isolation capabilities of the program.

APPENDIX I THE PROGRAM WITH EXAMPLE SOLUTIONS

```
      INTEGER A
      DIMENSION IS(20),Y(20),W(12),A(12,20),WV(8,12),
     1DEN(12),PNU(12),NS(12),YA(20),KAM(12,20),FUNMAG(101),SW(101),
     2TESTM(25),TESTW(2,25),NTREE(900,20),LTMP(12,20),
     3KA(12,12,20),KS(12,20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
  250 FORMAT(//5X,6H TIME=,F6.2,4H SEC)
 1100 CLCCK=ITIME(0)*.01
      TIME=ITIME(0)*.01-CLOCK
      INC=0
      READ(5,50)NI,MB,IGR,IPORT
      IF(NI.EQ.0)GO TO 1111
   50 FORMAT(4I10)
      WRITE(6,59)
   59 FORMAT (1H1,20X,'INPUT DATA'///)
      WRITE(6,7)NI,MB,IGR,IPORT
      ITERM=2*NI-1
    7 FORMAT(/10X,'NODE=',I2,5X,'EDGES=',I2,5X,'GR CONDITION=',I2,I3,
     1'-PORT'//,
     2'      EDGE NO.    NODE NUMBER    ADDMITTANCE    S-DEGR'/)
      DO 60 I=1,NI
      DO 60 J=1,MB
   60 A(I,J)=0
      JS=1
      DO 61 J=1,MB
      READ (5,51) LE,NX,NY,Y(LE),IS(LE)
   51 FORMAT (I10,2I3,F10.4,I5)
      WRITE(6,6)LE,NX,NY,Y(LE),IS(LE)
    6 FORMAT (3X,I10,2I6,2X,F12.4,4X,I4)
      YA(LE)=Y(LE)
      A(NX,LE)=1
      A(NY,LE)=1
      IF (IS(LE)) 62,61,61
   62 JS=JS+1
   61 CONTINUE
      DO 3 I=1,ITERM
    3 NS(I)=I-JS
      N1=1
      N2=2
      IF (IGR.EQ.1) GO TO 205
      N3=3
      N4=4
      GO TO 230
  205 N3=3
      N4=3
  230 CALL TCPOLO(N1,N2,N3,N4,ITERM,NI,MB,INC,JS)
      INC=INC+1
      TR=1.1
```

```
      DO 2 K=1,10
      TR=TR-0.2
      TX=TR*100.0
      DO 1 J=1,MB
      Y(J)=Y(J)+Y(J)*TR
      WRITE(6,4) J,TX
      CALL TCPOLO(N1,N2,N3,N4,ITERM,NI,MB,INC,JS)
      Y(J)=YA(J)
    1 CONTINUE
    2 CONTINUE
    4 FORMAT('1Y(',I2,') CHANGED',F4.0,'   PERCENT'///)
 1000 TIME=ITIME(0)*.01-CLOCK
      WRITE(6,250)TIME
      GO TO 1100
 1111 STOP
      END


      SUBROUTINE TCPOLO(N1,N2,N3,N4,ITERM,NI,MB,INC,JS)
      INTEGER A
      DIMENSION KAM(12,20),IS(20),Y(20),W(12),A(12,20),WV(8,12),
     1ISD(12),ISN(12),DEN(12),PNU(12),NS(12),YA(20),FUNMAG(101),SW(101),
     2TESTM(25),TESTW(2,25),NTREE(900,20),LTMP(12,20),KA(12,12,20),
     3KS(12,20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
  230 DO 190 L=2,7
      GO TO (12,12,13,14,15,16,17),L
   12 I1=N1
      I2=N3
      GO TO 200
   13 I1=N2
      I2=N4
      GO TO 200
   14 I1=N1
      I2=N2
      GO TO 200
   15 I1=N3
      I2=N4
      IF (I1.EQ.I2) GO TO 42
      GO TO 200
   42 N=1
      DO 72 I=1,ITERM
   72 WV(L,I)=0.
      GO TO 190
   16 I1=N1
      I2=N4
```

```
      GO TO 200
   17 I1=N2
      I2=N3
  200 CALL MODNET(I1,I2,NI,MB,N)
      CALL TREE(N,MB,JS,ITERM,W)
      DO 66 I=1,ITERM
   66 WV(L,I)=W(I)
  190 CONTINUE
      IF(INC.GT.0)GO TO 76
      WRITE(6,67)
   67 FORMAT (1H1,20X,'PRINT OUT THE NETWORK FUNTIONS'///)
   76 DO 86 I=1,ITERM
      PNU(I)=0.5*(WV(6,I)+WV(7,I)-WV(4,I)-WV(5,I))
   86 DEN(I)=WV(2,I)
      LK=1
      CALL RESULT(DEN,PNU,ISN,ISD,LK,INC,L1,ITERM)
      DO 87 I=1,ITERM
      PNU(I)=0.5*(WV(6,I)+WV(7,I)-WV(4,I)-WV(5,I))
   87 DEN(I)=WV(3,I)
      LK=2
      CALL RESULT(DEN,PNU,ISN,ISD,LK,INC,L2,ITERM)
      RETURN
      END


      SUBROUTINE RESULT(DEN,PNU,ISN,ISD,LK,INC,L,ITERM)
      INTEGER DASH,A
      DIMENSION DEN(12),PNU(12),LINE(100),ISN(12),ISD(12),TITLE(2,2),
     1PSIGN(12),QSIGN(12),C(12),Q(13),E(13),POL(13),DDD(12),QD(12),
     2ED(12),FUNMAG(101),SW(101),TESTM(25),TESTW(2,25),
     3A(12,20),WV(8,12),KAM(12,20),IS(20),Y(20),NTREE(900,20),
     4LTMP(12,20),KA(12,12,20),KS(12,20),YA(20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
      DATA BLANK/1H /,PLUS/1H+/,DASH/1H-/,
     1 TITLE/' V2/',' V1/','V1= ','V2= '/
   28 DO 29 J=1,ITERM
      IF (ABS(PNU(J)).GE.1000.) GO TO 30
      IF (ABS(DEN(J)).GE.1000.) GO TO 30
   29 CONTINUE
      GO TO 32
   30 DO 31 J=1,ITERM
      PNU(J)=PNU(J)/2.
      DEN(J)=DEN(J)/2.
   31 CONTINUE
      GO TO 28
   32 DO 80 J=1,ITERM
```

```
      C(J)=PNU(J)
      DDD(J)=DEN(J)
   80 CONTINUE
      K=0
      I=0
      ESP=1.E-4
      DO 33  J =1,ITERM
      IF(ABS(DEN(J)).LT.ESP) GO TO 34
      K=K+1
      DEN(K)=DEN(J)
      ISD(K)=J
      IF(INC.GT.0)GO TO 34
      IF  (K.EQ.1)  GO TO 11
      IF  (DEN(K))  11,12,12
   11 QSIGN(K)=BLANK
      GO TO 34
   12 QSIGN(K)=PLUS
   34 IF(ABS(PNU(J)).LT.ESP) GO TO 33
      I=I+1
      PNU(I)=PNU(J)
      ISN(I)=J
      IF(INC.GT.0)GO TO 33
      IF  (I.EQ.1)  GO TO 1
      IF  (PNU(I))  1,2,2
    1 PSIGN(I)=BLANK
      GO TO 33
    2 PSIGN(I)=PLUS
   33 CONTINUE
      IF  (ISD(1)-ISN(1))  20,20,21
   20 M=ISD(1)
      GO TO 25
   21 M=ISN(1)
   25 DO 36  J =1,K
      ISD(J)=ISD(J)-M
   36 KY=ISD(J)
      DO 37  J=1,I
      ISN(J)=ISN(J)-M
   37 KX=ISN(J)
      IF(INC.GT.0)GO TO 85
      ME=ITERM-M+1
      DO 81  J=1,ME
      C(J)=C(J+M-1)
      DDD(J)=DDD(J+M-1)
   81 CONTINUE
      DO 3  J=1,100
    3 LINE(J)=DASH
      WRITE(6,72)((PSIGN(J),PNU(J),ISN(J)),J=1,I)
      WRITE(6,73)(TITLE(LK,J),J=1,2),(LINE(M),M=1,100)
```

```
      WRITE(6,74)((QSIGN(J),DEN(J),ISD(J)),J=1,K)
   72 FORMAT(//20X,10(A1,F6.2,'S**',I2))
   73 FORMAT (10X,2A4,100A1)
   74 FORMAT(20X,10(A1,F6.2,'S**',I2))
      CALL POLRT(C,POL,KX,Q,E,IER)
      WRITE(6,75)IER,(TITLE(LK,J),J=1,2)
   75 FORMAT('0',I3,17X,2A4,' FOLLOWING ROOTS')
      WRITE (6,77)
   77 FORMAT (//T22,'NUMERATOR',T54,'REAL PART',T79,'IMAGINARY PART'//)
      IF(IER.GT.0) GOTO 83
      WRITE (6,78) ((Q(J),E(J)),J=1,KX)
   78 FORMAT (T47,E20.7,T72,E20.7)
   83 CALL POLRT(DDD,POL,KY,QD,ED,IER)
      WRITE (6,79)IER
   79 FORMAT(//I3,T22,'DENOMINATOR',T54,'REAL PART',T79,
     1'IMAGINARY PART'//)
      IF(IER.GT.0) GOTO 85
      WRITE (6,78) ((QD(J),ED(J)),J=1,KY)
   85 CALL TESFRQ(KX,KY,I,K,ISN,ISD,PNU,DEN,Q,E,QD,ED,INC,L,LK)
      RETURN
      END



      SUBROUTINE TESFRQ(KX,KY,I,K,ISN,ISD,PNU,DEN,Q,E,QD,ED,INC,L,LK)
      INTEGER A
      DIMENSION Q(13),QD(12),PNU(12),ISN(12),DEN(12),FUNMAG(101),
     1SW(101),TESTM(25),TESTW(2,25),ISD(12),E(13),ED(12),
     2A(12,20),WV(8,12),KAM(12,20),IS(20),Y(20),NTREE(900,20),
     3LTMP(12,20),KA(12,12,20),KS(12,20),YA(20)
      COMPLEX CNU(12),CDE(12),CNUSUM,CDESUM
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
      IF(INC.GT.0)GO TO 13
      RANGE=0.0
    1 IF(KX.EQ.0)GO TO 2
      KZ=KX
    6 KN=0
      DO 20 J=1,KZ
      IF(Q(J))10,25,20
   10 KN=KN+1
      Q(KN)=Q(J)
      GO TO 20
   25 IF(E(J).GE.0.0)GO TO 20
      KN=KN+1
      Q(KN)=E(J)
   20 CONTINUE
      IF(KN.EQ.0)GO TO 2
```

```
      IF(KN.EQ.1)GO TO 3
      L=1
      RANGE=Q(1)
      DO 50 J=2,KN
      RANGE=RANGE-Q(J)
      IF(RANGE)30,30,40
   40 L=J
   30 RANGE=Q(L)
   50 CONTINUE
      GO TO 2
    3 RANGE=Q(1)
    2 IF(KY.EQ.0) GO TO 5
      DO 70 J=1,KY
      E(J+1)=ED(J)
   70 Q(J+1)=QD(J)
      Q(1)=RANGE
      KZ=KY+1
      KY=0
      GO TO 6
    5 IF(RANGE.EQ.0.) GO TO 9
      IW=-INT(RANGE)*2
      IF(IW.EQ.0)IW=-INT(10.0*RANGE)
      IF(IW.EQ.0)IW=-INT(100.0*RANGE)
      IF(IW.EQ.0)GO TO 9
      DW=FLOAT(IW)
      GO TO 8
    9 DW=10.0
      DXW=0.1*DW
      KK=10
      GO TO 12
    8 DXW=0.01*DW
      KK=100
   12 DO 11 JJ=1,KK
      CNUSUM=CMPLX(0.,0.)
      DO 4 J=1,I
      CNU(J)=CMPLX(PNU(J),0.)*CMPLX(0.,DW)**ISN(J)
    4 CNUSUM=CNUSUM+CNU(J)
      CDESUM=CMPLX(0.,0.)
      DO 22 J=1,K
      CDE(J)=CMPLX(DEN(J),0.)*CMPLX(0.,DW)**ISD(J)
   22 CDESUM=CDESUM+CDE(J)
      FUNMAG(JJ)=CABS(CNUSUM/CDESUM)
      SW(JJ)=DW
      DW=DW-DXW
   11 CONTINUE
      TESTW(LK,1)=SW(1)
      TESTM(1)=FUNMAG(1)
      L=1
```

```
      K1=1
      ME=KK-2
      DO 16 J=1,ME
      DIF1=FUNMAG(J)-FUNMAG(J+1)
      IF(ABS(DIF1).LT.0.00001)DIF1=0.0
   14 DIF2=FUNMAG(J+1)-FUNMAG(J+2)
      IF(ABS(DIF2).LT.0.00001)DIF2=0.0
   15 IF(DIF1.GT.0.0.AND.DIF2.GT.0.0)GO TO 16
      IF(DIF1.LT.0.0.AND.DIF2.LT.0.0)GO TO 16
      IF(DIF1.EQ.0.0.AND.DIF2.EQ.0.0)GO TO 16
      L=L+1
      TESTM(L)=FUNMAG((J+K1)/2)
      TESTW(LK,L)=SW((J+K1)/2)
      L=L+1
      TESTM(L)=FUNMAG(J+1)
      TESTW(LK,L)=SW(J+1)
      K1=J
   16 CONTINUE
      L=L+1
      TESTM(L)=FUNMAG((K1+KK)/2)
      TESTW(LK,L)=SW((K1+KK)/2)
      L=L+1
      TESTM(L)=FUNMAG(KK)
      TESTW(LK,L)=SW(KK)
      WRITE (6,17)
   17 FORMAT('0',26X,'TEST MAGNITUDE',T49,'TEST FREQUENCY',//)
      WRITE(6,18)((TESTM(J),TESTW(LK,J)),J=1,L)
   18 FORMAT (T21,E20.7,T42,E20.7)
      GO TO 19
   13 WRITE(6,17)
      DO 19 JJ=1,L
      CNUSUM=CMPLX(0.,0.)
      DW=TESTW(LK,JJ)
      DO 21 J=1,I
      CNU(J)=CMPLX(PNU(J),0.)*CMPLX(0.,DW)**ISN(J)
   21 CNUSUM=CNUSUM+CNU(J)
      CDESUM=CMPLX(0.,0.)
      DO 23 J=1,K
      CDE(J)=CMPLX(DEN(J),0.)*CMPLX(0.,DW)**ISD(J)
   23 CDESUM=CDESUM+CDE(J)
      FUNMAG(JJ)=CABS(CNUSUM/CDESUM)
      SW(JJ)=DW
      WRITE(6,18)FUNMAG(JJ),SW(JJ)
   19 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MCDNET(I1,I2,NI,MB,N)
      INTEGER A
      DIMENSION A(12,20),KAM(12,20),
     1WV(8,12),FUNMAG(101),SW(101),TESTM(25),TESTW(2,25),IS(20),Y(20),
     2NTREE(900,20),LTMP(12,20),KA(12,12,20),KS(12,20),YA(20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
      DO 4 I =1,NI
      DO 4 J =1,MB
    4 KAM(I,J)=A(I,J)
      DO 3 J=1,MB
      KAM(I1,J)=A(I1,J)+A(I2,J)
      KAM(I2,J)=A(NI,J)
      IF (KAM(I1,J).LE.1) GO TO 3
      KAM(I1,J)=0
    3 CONTINUE
      N=NI-1
      RETURN
      END
```

```
      SUBROUTINE TREE(N,MB,JS,ITERM,W)
      INTEGER A
      DIMENSION KEY(12),KS(12,20),KAM(12,20),NTREE(900,20),LTMP(12,20),
     1KA(12,12,20),CONTL(12),A(12,20),WV(8,12),FUNMAG(101),
     2SW(101),TESTM(25),TESTW(2,25),YA(20),IS(20),W(12),Y(20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW,IS,Y,NTREE,LTMP,KA,KS,YA
      DO 58 K=1,ITERM
   58 W(K)=0.0
      NV=N-1
      KSUM=0
      DO 59 I=1,NV
      DO 59 J=1,MB
   59 KA(1,I,J)=KAM(I+1,J)
      DO 60 J=1,MB
   60 KS(1,J)=KAM(1,J)
      NX1=N-1
      NX2=N-2
      NX3=N-3
      NX4=N-4
      NX5=N-5
      NX6=N-6
      NX7=N-7
      NX8=N-8
      NX9=N-9
      NX10=N-10
      NX11=N-11
```

```
CONTL(1)=1.0
DO 100 I1=1,NX1
NX=NX1
M=1
IF (CONTL(M).EQ.0.0) GO TO 300
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX2.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 300
DO  99 I2=1,NX2
NX=NX2
M=2
IF (CONTL(M).EQ.0.0) GO TO 100
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX3.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 100
DO  98 I3=1,NX3
NX=NX3
M=3
IF (CONTL(M).EQ.0.0) GO TO  99
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX4.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 99
DO  97 I4=1,NX4
NX=NX4
M=4
IF (CONTL(M).EQ.0.0) GO TO 98
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX5.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 98
DO 96 I5 =1,NX5
NX=NX5
M=5
IF (CONTL(M).EQ.0.0) GO TO 97
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX6.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 97
DO 95 I6 =1,NX6
NX=NX6
M=6
IF (CONTL(M).EQ.0.0) GO TO 96
CALL NPART(M,MB,KEY,CONTL,NX)
IF (NX7.EQ.0) GO TO 190
IF (CONTL(M+1).EQ.0.0) GO TO 96
DO 94 I7 =1,NX7
M=7
IF (CONTL(M).EQ.0.0) GO TO 95
NX=NX7
CALL NPART(M,MB,KEY,CONTL,NX)
```

```
      IF (NX8.EQ.0) GO TO 190
      IF (CONTL(M+1).EQ.0.0) GO TO 95
      DO 93 I8 =1,NX8
      NX=NX8
      M=8
      IF (CONTL(M).EQ.0.0) GO TO 94
      CALL NPART(M,MB,KEY,CONTL,NX)
      IF (NX9.EQ.0) GO TO 190
      IF (CONTL(M+1).EQ.0.0) GO TO 94
      DO 92 I9 =1,NX9
      NX=NX9
      M=9
      IF (CONTL(M).EQ.0.0) GO TO 93
      CALL NPART(M,MB,KEY,CONTL,NX)
      IF(NX10.EQ.0) GO TO 190
      IF (CONTL(M+1).EQ.0.0) GO TO 93
      DO 91 I10=1,NX10
      NX=NX10
      M=10
      IF (CONTL(M).EQ.0.0) GO TO 92
      CALL NPART(M,MB,KEY,CONTL,NX)
      IF(NX11.EQ.0) GO TO 190
      IF (CONTL(M+1).EQ.0.0) GO TO 92
      DO 90 I11=1,NX11
      NX=NX11
      M=11
      IF (CONTL(M).EQ.0.0) GO TO 91
      CALL NPART(M,MB,KEY,CONTL,NX)
190   CONTINUE
      NTR=1
      DO 105 I=1,NV
105   NTR=NTR*KEY(I)
      CALL XTREE(KEY,NTR,NV,MB)
      DO 206 I=1,NTR
      V=1.0
      JJ=0
      DO 205 J=1,MB
      IF (NTREE(I,J).EQ.0) GO TO 205
      V=V*Y(J)
      JJ=JJ+IS(J)
 205  CONTINUE
      W(JJ+JS)=V+W(JJ+JS)
 206  CONTINUE
      GO TO (100,99,98,97,96,95,94,93,92,91,90,89,88,87),M
  87  CONTINUE
  88  CONTINUE
  89  CONTINUE
  90  CONTINUE
```

```
91   CONTINUE
92   CONTINUE
93   CONTINUE
94   CONTINUE
95   CONTINUE
96   CONTINUE
97   CONTINUE
98   CONTINUE
99   CONTINUE
100  CONTINUE
300  CONTINUE
     RETURN
     END


     SUBROUTINE  NPART(M,MB,KEY,CONTL,NX)
     INTEGER A
     DIMENSION KEY(12),KS(12,20),KA(12,12,20),LTMP(12,20),
    1CONTL(12),A(12,20),WV(8,12),KAM(12,20),FUNMAG(101),
    2SW(101),TESTM(25),TESTW(2,25),IS(20),Y(20),NTREE(900,20),YA(20)
     COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW, IS,Y,NTREE,LTMP,KA,KS,YA
     KEY(M)=0
     KEND=0
     KCPR=0
     NTEST=0
     DO 2  J=1,MB
     K=J
     IF  (KS(M,J).EQ.0)  GO TO 2
     GO  TO  9
   2 CONTINUE
   9 DO 3  I=1,NX
     IK=I
     IF(KA(M,I,K).EQ.0)GO TO 3
     GO  TO 15
   3 CONTINUE
  15 DO 72  J=1,MB
     LTMP(M,J)=KS(M,J)*KA(M,IK,J)
     KEY(M)=KEY(M)+LTMP(M,J)
     KA(M,IK,J)=KA(M,IK,J)-LTMP(M,J)
     KS(M,J)=KS(M,J)-LTMP(M,J)
     KS(M+1,J)=KS(M,J)+KA(M,IK,J)
     KEND=KEND+KS(M,J)
     KCPR=KCPR+KA(M,IK,J)
     NTEST=NTEST+KS(M+1,J)
  72 CONTINUE
     DO 12  J=1,MB
```

```
      ITEMP=KA(M,NX,J)
      KA(M,NX,J)=KA(M,IK,J)
   12 KA(M,IK,J)=ITEMP
      K=NX-1
      DO 66  I=1,K
      DO 66  J=1,MB
   66 KA(M+1,I,J)=KA(M,I,J)
      CONTL(M)=KEND*KCPR
      CONTL(M+1)=NTEST
      RETURN
      END


      SUBROUTINE  XTREE(KEY,NTR,NV,MB)
      INTEGER A
      DIMENSION          LTMP(12,20),NTREE(900,20), KEY(12),
     1A(12,20),WV(8,12),KAM(12,20),FUNMAG(101),SW(101),TESTM(25),
     2TESTW(2,25),IS(20),Y(20),KA(12,12,20),KS(12,20),YA(20)
      COMMON A,WV,KAM,FUNMAG,SW,TESTM,TESTW, IS,Y,NTREE,LTMP,KA,KS,YA
      DO 20  I=1,NTR
      DO 20  J=1,MB
   20 NTREE(I,J)=0
      MP=1
      DO 26  I=1,NV
      MP=MP*KEY(I)
      MQ=NTR/MP
      MS=MQ*KEY(I)
      M=1
      DO 26  J=1,MB
      IF(LTMP(I,J)-1)26,30,26
   30 DO 28  IM=M,NTR,MS
      DO 28  IJ=1,MQ
      IX=IM+IJ-1
   28 NTREE(IX,J)=1
      M=M+MQ
   26 CONTINUE
      RETURN
      END
```

INPUT DATA

NODE= 4 EDGES= 5 GR CONDITION= 2 2-PORT

EDGE NO.	NODE NUMBER		ADMITTANCE	S-DEGR
1	1	2	1.0000	1
2	2	3	2.0000	-1
3	1	4	1.0000	0
4	2	4	1.0000	1
5	3	4	1.0000	0

```
            -2.00S** 0+  1.00S** 2
V2/V1= ------------------------------------------------------
             4.00S** 0+  2.00S** 1+  4.00S** 2+  1.00S** 3

V2/V1=  FOLLOWING ROOTS
```

NUMERATOR

REAL PART	IMAGINARY PART
-0.1414213E 01	0.0
0.1414213E 01	0.0

DENOMINATOR

REAL PART	IMAGINARY PART
-0.3751101E 01	0.0
-0.1244497E 00	-0.1025118E 01
-0.1244497E 00	0.1025118E 01

TEST MAGNITUDE	TEST FREQUENCY
0.1535858E 00	0.6000000E 01
0.2450153E 00	0.3539983E 01
0.3064734E 01	0.1019965E 01
0.8604361E 00	0.5999652E 00
0.5024794E 00	0.5996521E-01

```
            -2.00S** 0+  1.00S** 2
V1/V2= ---------------------------------------------------
             2.00S** 0+  3.00S** 1+  1.00S** 2

V1/V2=  FOLLOWING ROOTS

                        NUMERATOR

             REAL PART                IMAGINARY PART

           -0.1414213E 01              0.0
            0.1414213E 01              0.0

                        DENOMINATOR

             REAL PART                IMAGINARY PART

           -0.1000000E 01              0.0
           -0.2000000E 01              0.0

              TEST MAGNITUDE          TEST FREQUENCY

              0.9761862E 00           0.4000000E 01
              0.9605792E 00           0.2720001E 01
              0.9428138E 00           0.1400002E 01
              0.9591744E 00           0.7600028E 00
              0.9997985E 00           0.4000244E-01
```

Y(1) CHANGED 90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1571577E 00	0.6000000E 01
0.2497683E 00	0.3539983E 01
0.1955035E 01	0.1019965E 01
0.1297297E 01	0.5999652E 00
0.5041096E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9451243E 00	0.4000000E 01
0.9035180E 00	0.2720001E 01
0.8250669E 00	0.1400002E 01
0.8242266E 00	0.7600028E 00
0.9984386E 00	0.4000244E-01

Y(2) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1682889E 00	0.6000000E 01
0.3106483E 00	0.3539983E 01
0.1089228E 01	0.1019965E 01
0.6403168E 00	0.5999652E 00
0.5011960E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.8703982E 00	0.4000000E 01
0.8268894E 00	0.2720001E 01
0.8267125E 00	0.1400002E 01
0.8993663E 00	0.7600028E 00
0.9995654E 00	0.4000244E-01

Y(3) CHANGEC 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1382935E 00	0.6000000E 01
0.2132842E 00	0.3539983E 01
0.4809584E 01	0.1019965E 01
0.1083199E 01	0.5999652E 00
0.6580175E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9997945E 00	0.4000000E 01
0.9997042E 00	0.2720001E 01
0.9997039E 00	0.1400002E 01
0.9998481E 00	0.7600028E 00
0.9999987E 00	0.4000244E-01

Y(4) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8668274E-01	0.6000000E 01
0.1472809E 00	0.3539983E 01
0.1103167E 01	0.1019965E 01
0.8824603E 00	0.5999652E 00
0.5027032E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761862E 00	0.4000000E 01
0.9605792E 00	0.2720001E 01
0.9428138E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2446198E 00	0.6000000E 01
0.3370683E 00	0.3539983E 01
0.3951365E 01	0.1019965E 01
0.6988586E 00	0.5999652E 00
0.3471797E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9999227E 00	0.4000000E 01
0.9998555E 00	0.2720001E 01
0.9997002E 00	0.1400002E 01
0.9996979E 00	0.7600028E 00
0.9999968E 00	0.4000244E-01

Y(1) CHANGED 70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1568188E 00	0.6000000E 01
0.2495043E 00	0.3539983E 01
0.2305066E 01	0.1019965E 01
0.1177353E 01	0.5999652E 00
0.5037468E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9499762E 00	0.4000000E 01
0.9126641E 00	0.2720001E 01
0.8460310E 00	0.1400002E 01
0.8530629E 00	0.7600028E 00
0.9988521E 00	0.4000244E-01

Y(2) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1649079E 00	0.6000000E 01
0.2947214E 00	0.3539983E 01
0.1243282E 01	0.1019965E 01
0.6640707E 00	0.5999652E 00
0.5013635E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.8962664E 00	0.4000000E 01
0.8557758E 00	0.2720001E 01
0.8472864E 00	0.1400002E 01
0.9089834E 00	0.7600028E 00
0.9996017E 00	0.4000244E-01

Y(3) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1416780E 00	0.6000000E 01
0.2195111E 00	0.3539983E 01
0.4428083E 01	0.1019965E 01
0.1046303E 01	0.5999652E 00
0.6324131E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9980912E 00	0.4000000E 01
0.9971556E 00	0.2720001E 01
0.9969437E 00	0.1400002E 01
0.9983603E 00	0.7600028E 00
0.9999932E 00	0.4000244E-01

Y(4) CHANGED 70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9604961E-01	0.6000000E 01
0.1617543E 00	0.3539983E 01
0.1310034E 01	0.1019965E 01
0.8903191E 00	0.5999652E 00
0.5026858E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761862E 00	0.4000000E 01
0.9605792E 00	0.2720001E 01
0.9428138E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2272601E 00	0.6000000E 01
0.3210862E 00	0.3539983E 01
0.3758165E 01	0.1019965E 01
0.7268347E 00	0.5999652E 00
0.3727506E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9991560E 00	0.4000000E 01
0.9984355E 00	0.2720001E 01
0.9969112E 00	0.1400002E 01
0.9970890E 00	0.7600028E 00
0.9999818E 00	0.4000244E-01

Y(1) CHANGED 50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1563293E 00	0.6000000E 01
0.2489942E 00	0.3539983E 01
0.2776137E 01	0.1019965E 01
0.1072525E 01	0.5999652E 00
0.5033844E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9557790E 00	0.4000000E 01
0.92235095E 00	0.2720001E 01
0.8699712E 00	0.1400002E 01
0.8834698E 00	0.7600028E 00
0.9992021E 00	0.4000244E-01

Y(2) CHANGED 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1615934E 00	0.6000000E 01
0.2796050E 00	0.3539983E 01
0.1487673E 01	0.1019965E 01
0.6950154E 00	0.5999652E 00
0.5015759E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9216344E 00	0.4000000E 01
0.8860688E 00	0.2720001E 01
0.8708239E 00	0.1400002E 01
0.9203748E 00	0.7600028E 00
0.9996429E 00	0.4000244E-01

Y(3) CHANGED 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1451017E 00	0.6000000E 01
0.2262067E 00	0.3539983E 01
0.4042809E 01	0.1019965E 01
0.1003551E 01	0.5999652E 00
0.6027126E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9945040E 00	0.4000000E 01
0.9915546E 00	0.2720001E 01
0.9901871E 00	0.1400002E 01
0.9944057E 00	0.7600028E 00
0.9999763E 00	0.4000244E-01

Y(4) CHANGED 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1076474E 00	0.6000000E 01
0.1793061E 00	0.3539983E 01
0.1602461E 01	0.1019965E 01
0.8907486E 00	0.5999652E 00
0.5026495E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761862E 00	0.4000000E 01
0.9605792E 00	0.2720001E 01
0.9428138E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED 50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2083510E 00	0.6000000E 01
0.3028987E 00	0.3539983E 01
0.3562678E 01	0.1019965E 01
0.7586280E 00	0.5999652E 00
0.4024099E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9970541E 00	0.4000000E 01
0.9946513E 00	0.2720001E 01
0.9901082E 00	0.1400002E 01
0.9913261E 00	0.7600028E 00
0.9999489E 00	0.4000244E-01

Y(1) CHANGED 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1555939E 00	0.6000000E 01
0.2480578E 00	0.3539983E 01
0.3266519E 01	0.1019965E 01
0.9801356E 00	0.5999652E 00
0.5030223E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9627877E 00	0.4000000E 01
0.9364534E 00	0.2720001E 01
0.8970934E 00	0.1400002E 01
0.9146255E 00	0.7600028E 00
0.9994882E 00	0.4000244E-01

Y(2) CHANGED 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1583434E 00	0.6000000E 01
0.2652452E 00	0.3539983E 01
0.1916081E 01	0.1019965E 01
0.7412632E 00	0.5999652E 00
0.5018538E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9455878E 00	0.4000000E 01
0.9169061E 00	0.2720001E 01
0.8975540E 00	0.1400002E 01
0.9339494E 00	0.7600028E 00
0.9996966E 00	0.4000244E-01

Y(3) CHANGED 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1485305E 00	0.6000000E 01
0.2333826E 00	0.3539983E 01
0.3654004E 01	0.1019965E 01
0.9535120E 00	0.5999652E 00
0.5678477E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9888568E 00	0.4000000E 01
0.9823465E 00	0.2720001E 01
0.9776763E 00	0.1400002E 01
0.9862715E 00	0.7600028E 00
0.9999416E 00	0.4000244E-01

Y(4) CHANGED 30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1223608E 00	0.6000000E 01
0.2010003E 00	0.3539983E 01
0.2033114E 01	0.1019965E 01
0.8837183E 00	0.5999652E 00
0.5025951E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761862E 00	0.4000000E 01
0.9605792E 00	0.2720001E 01
0.9428138E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGEC 30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1877794E 00	0.6000000E 01
0.2821126E 00	0.3539983E 01
0.3365021E 01	0.1019965E 01
0.7950172E 00	0.5999652E 00
0.4372222E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9925428E 00	0.4000000E 01
0.9868339E 00	0.2720001E 01
0.9775620E 00	0.1400002E 01
0.9818076E 00	0.7600028E 00
0.9999019E 00	0.4000244E-01

Y(1) CHANGED 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1544310E 00	0.6000000E 01
0.2463512E 00	0.3539983E 01
0.3317973E 01	0.1019965E 01
0.8980995E 00	0.5999652E 00
0.5026603E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9712963E 00	0.4000000E 01
0.9518829E 00	0.2720001E 01
0.9271165E 00	0.1400002E 01
0.9450124E 00	0.7600028E 00
0.9997119E 00	0.4000244E-01

Y(2) CHANGED 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1551563E 00	0.6000000E 01
0.2515919E 00	0.3539983E 01
0.2685353E 01	0.1019965E 01
0.8102869E 00	0.5999652E 00
0.5022331E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9669362E 00	0.4000000E 01
0.9467561E 00	0.2720001E 01
0.9272414E 00	0.1400002E 01
0.9500952E 00	0.7600028E 00
0.9997619E 00	0.4000244E-01

Y(3) CHANGEC 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1519213E 00	0.6000000E 01
0.2410282E 00	0.3539983E 01
0.3261923E 01	0.1019965E 01
0.8942762E 00	0.5999652E 00
0.5263431E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
C.9809929E 00	0.4000000E 01
0.9689812E 00	0.2720001E 01
0.9570623E 00	0.1400002E 01
0.9709905E 00	0.7600028E 00
0.9998654E 00	0.4000244E-01

Y(4) CHANGED 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1415948E 00	0.6000000E 01
0.2284288E 00	0.3539983E 01
0.2670909E 01	0.1019965E 01
0.8697417E 00	0.5999652E 00
0.5025228E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761862E 00	0.40000C0E 01
0.9605792E 00	0.2720001E 01
0.9428138E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED 10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1654430E 00	0.6000000E 01
0.2582592E 00	0.3539983E 01
0.3165315E 01	0.1019965E 01
0.8369845E 00	0.5999652E 00
0.4786579E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9835457E 00	0.4000000E 01
0.9720633E 00	0.2720001E 01
0.9569851E 00	0.1400002E 01
0.9679276E 00	0.7600028E 00
0.9998380E 00	0.4000244E-01

Y(1) CHANGED-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1524668E 00	0.6000000E 01
0.2431798E 00	0.3539983E 01
0.2703896E 01	0.1019965E 01
0.8247721E 00	0.5999652E 00
0.5022985E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9814896E 00	0.4000000E 01
0.9698415E 00	0.2720001E 01
0.9584686E 00	0.1400002E 01
0.9721017E 00	0.7600028E 00
0.9998720E 00	0.4000244E-01

Y(2) CHANGED-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1520301E 00	0.6000000E 01
0.2385980E 00	0.3539983E 01
0.2968597E 01	0.1019965E 01
0.9284009E 00	0.5999652E 00
0.5027812E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9842208E 00	0.4000000E 01
0.9731404E 00	0.2720001E 01
0.9583858E 00	0.1400002E 01
0.9688235E 00	0.7600028E 00
0.9998410E 00	0.4000244E-01

Y(3) CHANGED-10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1552191E 00	0.6000000E 01
0.2490999E 00	0.3539983E 01
0.2866825E 01	0.1019965E 01
0.8232610E 00	0.5999652E 00
0.4761047E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9707794E 00	0.4000000E 01
0.9509562E 00	0.2720001E 01
0.9253895E 00	0.1400002E 01
0.9433815E 00	0.7600028E 00
0.9997007E 00	0.4000244E-01

Y(4) CHANGED-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1677007E 00	0.6000000E 01
0.2640566E 00	0.3539983E 01
0.3446352E 01	0.1019965E 01
0.8497797E 00	0.5999652E 00
0.5024318E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761856E 00	0.4000000E 01
0.9605784E 00	0.2720001E 01
0.9428135E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED-10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1412576E 00	0.6000000E 01
0.2307946E 00	0.3539983E 01
0.2963688E 01	0.1019965E 01
0.8857711E 00	0.5999652E 00
0.5288053E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9658417E 00	0.4000000E 01
0.9451599E 00	0.2720001E 01
0.9255307E 00	0.1400002E 01
0.9491272E 00	0.7600028E 00
0.9997581E 00	0.4000244E-01

Y(1) CHANGED-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1488422E 00	0.6000000E 01
0.2370372E 00	0.3539983E 01
0.1980884E 01	0.1019965E 01
0.7588429E 00	0.5999652E 00
0.5019372E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9927329E 00	0.4000000E 01
0.9887089E 00	0.2720001E 01
0.9864880E 00	0.1400002E 01
0.9920997E 00	0.7600028E 00
0.9999679E 00	0.4000244E-01

Y(2) CHANGED-30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1489634E 00	0.6000000E 01
0.2262213E 00	0.3539983E 01
0.1730876E 01	0.1019965E 01
0.1176073E 01	0.5999652E 00
0.5036448E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9957982E 00	0.4000000E 01
0.9924399E 00	0.2720001E 01
0.9863932E 00	0.1400002E 01
0.9883897E 00	0.7600028E 00
0.9999341E 00	0.4000244E-01

Y(3) CHANGED-30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1583592E 00	0.6000000E 01
0.2575015E 00	0.3539983E 01
0.2468990E 01	0.1019965E 01
0.7369199E 00	0.5999652E 00
0.4140531E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9581276E 00	0.4000000E 01
0.9278695E 00	0.2720001E 01
0.8792915E 00	0.1400002E 01
0.8945716E 00	0.7600028E 00
0.9993109E 00	0.4000244E-01

Y(4) CHANGED-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2048512E 00	0.6000000E 01
0.3118351E 00	0.3539983E 01
0.3676844E 01	0.1019965E 01
0.8250701E 00	0.5999652E 00
0.5023233E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761856E 00	0.4000000E 01
0.9605784E 00	0.2720001E 01
0.9428135E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1151702E 00	0.6000000E 01
0.1991040E 00	0.3539983E 01
0.2760275E 01	0.1019965E 01
0.9429335E 00	0.5999652E 00
0.5907325E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9304067E 00	0.4000000E 01
0.8970816E 00	0.2720001E 01
0.8800005E 00	0.1400002E 01
0.9249494E 00	0.7600028E 00
0.9996621E 00	0.4000244E-01

Y(1) CHANGED-50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1413081E 00	0.6000000E 01
0.2244155E 00	0.3539983E 01
0.1442825E 01	0.1019965E 01
0.6992468E 00	0.5999652E 00
0.5015761E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9999996E 00	0.4000000E 01
0.9999995E 00	0.2720001E 01
0.9999993E 00	0.1400002E 01
0.9999991E 00	0.7600028E 00
0.9999987E 00	0.4000244E-01

Y(2) CHANGED-50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1459544E 00	0.6000000E 01
0.2144216E 00	0.3539983E 01
0.9438505E 00	0.1019965E 01
0.2002441E 01	0.5999652E C0
0.5052037E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9999977E 00	0.4000000E 01
0.9999990E 00	0.2720001E 01
0.9999999E 00	0.1400002E 01
0.9999996E 00	0.7600028E 00
0.9999988E 00	0.4000244E-01

Y(3) CHANGED-50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1612644E 00	0.6000000E 01
0.2660570E 00	0.3539983E 01
0.2068706E 01	0.1019965E 01
0.6303209E 00	0.5999652E 00
0.3354700E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9429886E 00	0.4000000E 01
0.8994738E 00	0.2720001E 01
0.8155903E 00	0.1400002E 01
0.8105271E 00	0.7600028E 00
0.9982086E 00	0.4000244E-01

Y(4) CHANGED-50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2608619E 00	0.6000000E 01
0.3782318E 00	0.3539983E 01
0.3021946E 01	0.1019965E 01
0.7969374E 00	0.5999652E 00
0.5021968E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761856E 00	0.4000000E 01
0.9605784E 00	0.2720001E 01
0.9428135E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED-50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8716983E-01	0.6000000E 01
0.1625214E 00	0.3539983E 01
0.2555217E 01	0.1019965E 01
0.1010388E 01	0.5999652E 00
0.6691380E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.8574918E 00	0.4000000E 01
0.8131152E 00	0.2720001E 01
0.8174232E 00	0.1400002E 01
0.8951126E 00	0.7600028E 00
0.9995491E 00	0.4000244E-01

Y(1) CHANGED-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1230766E 00	0.6000000E 01
0.1968862E 00	0.3539983E 01
0.1073212E 01	0.1019965E 01
0.6451144E 00	0.5999652E 00
0.5012152E C0	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9734161E 00	0.4000000E 01
0.9683270E 00	0.2720001E 01
0.9773800E 00	0.1400002E 01
0.9903579E 00	0.7600028E 00
0.9999669E 00	0.4000244E-01

Y(2) CHANGED-70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1430016E 00	0.6000000E 01
0.2031623E 00	0.3539983E 01
0.5476562E 00	0.1019965E 01
0.3431462E 01	0.5999652E 00
0.5088666E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9953855E 00	0.4000000E 01
0.9908738E 00	0.2720001E 01
0.9768999E 00	0.1400002E 01
0.9682562E 00	0.7600028E 00
0.9996454E 00	0.4000244E-01

Y(3) CHANGED-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1638488E 00	0.6000000E 01
0.2744791E 00	0.3539983E 01
0.1666264E 01	0.1019965E 01
0.4965511E 00	0.5999652E 00
0.2327410E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9253681E 00	0.4000000E 01
0.8657379E 00	0.2720001E 01
0.7323852E 00	0.1400002E 01
0.6736280E 00	0.7600028E 00
0.9936692E 00	0.4000244E-01

Y(4) CHANGEC-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.3502100E 00	0.6000000E 01
0.4734583E 00	0.3539983E 01
0.2289363E 01	0.1019965E 01
0.7666445E 00	0.5999652E 00
0.5020522E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761856E 00	0.4000000E 01
0.9605784E 00	0.2720001E 01
0.9428135E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGED-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.5730216E-01	0.6000000E 01
0.1203857E C0	0.3539983E 01
0.2348657E 01	0.1019965E 01
0.1090384E 01	0.5999652E 00
C.7715993E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.7071046E 00	0.4000000E 01
0.6740592E 00	0.2720001E 01
0.7360658E 00	0.1400002E 01
0.8595725E 00	0.7600028E 00
0.9994219E 00	0.4000244E-01

Y(1) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.7386827E-01	0.6000000E 01
0.1371645E 00	0.3539983E 01
0.8147975E 00	0.1019965E 01
0.5957295E 00	0.5999652E 00
0.5008546E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.7474074E 00	0.4000000E 01
0.7830759E 00	0.2720001E 01
0.8908274E 00	0.1400002E 01
0.9590124E 00	0.7600028E 00
0.9998704E 00	0.4000244E-01

Y(2) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1401039E 00	0.6000000E 01
0.1924099E 00	0.3539983E 01
0.3215172E 00	0.1019965E 01
0.5362288E 00	0.5999652E 00
0.5277279E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9810433E 00	0.4000000E 01
0.9613555E 00	0.2720001E 01
0.8877540E 00	0.1400002E 01
0.7877788E 00	0.7600028E 00
0.9876337E 00	0.4000244E-01

Y(3) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.1660182E 00	0.6000000E 01
0.2823303E 00	0.3539983E 01
0.1261973E 01	0.1019965E 01
0.3259692E 00	0.5999652E 00
0.9273881E-01	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9053223E 00	0.4000000E 01
0.8268704E 00	0.2720001E 01
0.6303725E 00	0.1400002E 01
0.4741288E 00	0.7600028E 00
0.9357086E 00	0.4000244E-01

Y(4) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.4876925E 00	0.6000000E 01
0.6089728E 00	0.3539983E 01
0.1773738E 01	0.1019965E 01
0.7352803E 00	0.5999652E 00
0.5018891E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9761856E 00	0.4000000E 01
0.9605784E 00	0.2720001E 01
0.9428135E 00	0.1400002E 01
0.9591744E 00	0.7600028E 00
0.9997985E 00	0.4000244E-01

Y(5) CHANGEC-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2568222E-01	0.6000000E 01
0.7214075E-01	0.3539983E 01
0.2140754E 01	0.1019965E 01
0.1185218E 01	0.5999652E 00
0.9111781E 00	0.5996521E-01

TEST MAGNITUDE	TEST FREQUENCY
0.4280840E 00	0.4000000E 01
0.4683987E 00	0.2720001E 01
0.6366402E 00	0.1400002E 01
0.8185626E 00	0.7600028E 00
0.9992775E 00	0.4000244E-01

TIME= 13.26 SEC

INPUT DATA

NODE= 5 EDGES= 5 GR CONDITION= 2 2-PORT

EDGE NO.	NODE NUMBER		ADMITTANCE	S-DEGR
1	1	5	1.0000	1
2	3	5	0.2500	0
3	2	5	2.5000	1
4	3	4	2.5000	1
5	2	4	0.5000	0

```
           6.25S** 2
V2/V1= ---------------------------------------------
           0.63S** 0+  7.19S** 1+  6.25S** 2

V2/V1=  FOLLOWING ROOTS

                         NUMERATOR
            REAL PART                   IMAGINARY PART

           0.0                           0.0
           0.0                           0.0

                         DENOMINATOR
            REAL PART                   IMAGINARY PART

          -0.9476566E-01                 0.0
          -0.1055235E 01                 0.0
             TEST MAGNITUDE             TEST FREQUENCY

             0.8834510E 00              0.2000000E 01
             0.6920124E 00              0.1019978E 01
             0.3903799E-02              0.1997574E-01
```

```
                6.25S** 1
V1/V2= -----------------------------------------------------------
                1.25S** 0+  6.25S** 1

V1/V2=  FOLLOWING ROOTS

                          NUMERATOR
            REAL PART                 IMAGINARY PART

           0.0                         0.0

                          DENOMINATOR
            REAL PART                 IMAGINARY PART

          -0.2000001E 00               0.0
              TEST MAGNITUDE          TEST FREQUENCY

              0.9950370E 00           0.2000000E 01
              0.9813122E 00           0.1019978E 01
              0.9938407E-01           0.1997574E-01
```

Y(1) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9399887E 00	0.2000000E 01
0.8141952E 00	0.1019978E 01
0.7309314E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813117E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(2) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8512831E 00	0.2000000E 01
0.6343126E 00	0.1019978E 01
0.2082839E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9824240E 00	0.2000000E 01
0.9370797E 00	0.1019978E 01
0.5249525E-01	0.1997574E-01

Y(3) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8978077E 00	0.2000000E 01
0.7199913E 00	0.1019978E 01
0.5064532E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9970995E 00	0.2000000E 01
0.9889882E 00	0.1019978E 01
0.1297687E 00	0.1997574E-01

Y(4) CHANGED 90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8978077E 00	0.2000000E 01
0.7199911E 00	0.1019978E 01
0.5064532E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9970995E 00	0.2000000E 01
0.9889882E 00	0.1019978E 01
0.1297687E 00	0.1997574E-01

Y(5) CHANGED 90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.7317309E 00	0.2000000E 01
0.4788756E 00	0.1019978E 01
0.2061095E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9334389E 00	0.2000000E 01
0.7980239E 00	0.1019978E 01
0.6563760E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938413E-01	0.1997574E-01

Y(2) CHANGEC 70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8588477E 00	0.20000C0E 01
0.6471961E 00	0.1019978E 01
0.2324624E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9858556E 00	0.2000000E 01
0.9486811E 00	0.1019978E 01
0.5865101E-01	0.1997574E-01

Y(3) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8959848E 00	0.2000000E 01
0.7163311E 00	0.1019978E 01
0.4875697E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9968612E 00	0.2000000E 01
0.9880918E 00	0.1019978E 01
0.1247898E 00	0.1997574E-01

Y(4) CHANGED 70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8959848E 00	0.2000000E 01
0.7163310E 00	0.1019978E 01
0.4875697E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9968612E 00	0.2000000E 01
0.9880918E 00	0.1019978E 01
0.1247898E 00	0.1997574E-01

Y(5) CHANGED 70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.7649634E 00	0.2000000E 01
0.5167150E 00	0.1019978E 01
0.2302700E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGEC 50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9247195E 00	0.2000000E 01
0.7774323E 00	0.1019978E 01
0.5811408E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938413E-01	0.1997574E-01

Y(2) CHANGED 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8661938E 00	0.2000000E 01
0.6600986E 00	0.1019978E 01
0.2629461E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9889364E 00	0.2000000E 01
0.9593631E 00	0.1019978E 01
0.6643850E-01	0.1997574E-01

Y(3) CHANGED 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8936510E 00	0.2000000E 01
0.7116931E 00	0.1019978E 01
0.4655510E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9965459E 00	0.2000000E 01
0.9869108E 00	0.1019978E 01
0.1190026E 00	0.1997574E-01

Y(4) CHANGED 50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8936510E 00	0.2000000E 01
0.7116931E 00	0.1019978E 01
0.4655510E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9965459E 00	0.2000000E 01
0.9869108E 00	0.1019978E 01
0.1190026E 00	0.1997574E-01

Y(5) CHANGEC 50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.7990016E 00	0.20000C0E 01
0.5596181E 00	0.1019978E 01
0.2608433E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED 30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9126789E 00	0.2000000E 01
0.7505969E 00	0.1019978E 01
0.5052723E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813118E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(2) CHANGED 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8732989E 00	0.2000000E 01
0.6729591E 00	0.1019978E 01
0.3025456E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9916552E 00	0.2000000E 01
0.9690125E 00	0.1019978E 01
0.7660383E-01	0.1997574E-01

Y(3) CHANGEC 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8905603E 00	0.20000C0E 01
0.7056291E 00	0.1019978E 01
0.4395507E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9961098E 00	0.20000C0E 01
0.9852865E 00	0.1019978E 01
0.1121933E 00	0.1997574E-01

Y(4) CHANGED 30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8905603E 00	0.2000000E 01
0.7056291E 00	0.1019978E 01
0.4395507E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9961098E 00	0.20000C0E 01
0.9852865E 00	0.1019978E 01
0.1121933E 00	0.1997574E-01

Y(5) CHANGED 30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8332881E 00	0.2000000E 01
0.6081428E 00	0.1019978E 01
0.3007716E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8952699E 00	0.2000000E 01
0.7146854E 00	0.1019978E 01
0.4288137E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(2) CHANGED 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8801392E 00	0.2000000E 01
0.6857063E 00	0.1019978E 01
0.3560033E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9940042E 00	0.2000000E 01
0.9775196E 00	0.1019978E 01
0.9042674E-01	0.1997574E-01

Y(3) CHANGED 10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8862761E 00	0.2000000E 01
0.6973698E 00	0.1019978E 01
0.4083920E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9954750E 00	0.2000000E 01
0.9829302E 00	0.1019978E 01
0.1040666E 00	0.1997574E-01

Y(4) CHANGEC 10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8862761E 00	0.20000C0E 01
0.6973698E 00	0.1019978E 01
0.4083920E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9954750E 00	0.2000000E 01
0.9829302E 00	0.1019978E 01
0.1040666E 00	0.1997574E-01

Y(5) CHANGED 10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8670590E 00	0.2000000E 01
0.6626046E 00	0.1019978E 01
0.3551194E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8685815E 00	0.2000000E 01
0.6652025E 00	0.1019978E 01
0.3518155E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(2) CHANGED-10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8866886E 00	0.2000000E 01
0.6982601E 00	0.1019978E 01
0.4319619E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9959737E 00	0.2000000E 01
0.9847830E 00	0.1019978E 01
0.1102991E 00	0.1997574E-01

Y(3) CHANGED-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8799572E 00	0.2000000E 01
0.6854819E 00	0.1019978E 01
0.3703910E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9944749E 00	0.2000000E 01
0.9792445E 00	0.1019978E 01
0.9420097E-01	0.1997574E-01

Y(4) CHANGEC-10. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8799572E 00	0.2000000E 01
0.6854819E 00	0.1019978E 01
0.3703910E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9944749E 00	0.20000C0E 01
0.9792445E 00	0.1019978E 01
0.9420097E-01	0.1997574E-01

Y(5) CHANGED-10.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8993308E 00	0.2000000E 01
0.7227271E 00	0.1019978E 01
0.4334033E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGEC-30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8244705E 00	0.2000000E 01
0.5949271E 00	0.1019978E 01
0.2743248E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.200C0C0E 01
0.9813122E 00	0.1019978E 01
C.9938407E-01	0.1997574E-01

Y(2) CHANGEC-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8929230E 00	0.2000000E 01
0.7105331E 00	0.1019978E 01
0.5478293E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9975581E 00	0.20000C0E C1
0.9907107E 00	0.1019978E 01
0.1412531E 00	0.1997574E-01

Y(3) CHANGED-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8697436E 00	0.2000000E 01
0.6669707E 00	0.1019978E 01
0.3230457E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9927079E 00	0.2000000E 01
0.9728046E 00	0.1019978E 01
0.8197600E-01	0.1997574E-01

Y(4) CHANGED-30. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8697436E 00	0.2000000E 01
0.6669707E 00	0.1019978E 01
0.3230457E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9927079E 00	0.2000000E 01
0.9728046E 00	0.1019978E 01
0.8197600E-01	0.1997574E-01

Y(5) CHANGED-30.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9289129E 00	0.2000000E 01
0.7870545E 00	0.1019978E 01
0.5558569E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED-50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.7443217E 00	0.2000000E 01
0.4925176E 00	0.1019978E 01
0.1963945E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(2) CHANGED-50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8988194E 00	0.2000000E 01
0.7224288E 00	0.1019978E 01
0.7436145E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9987518E 00	0.2000000E 01
0.9952279E 00	0.1019978E 01
0.1958873E 00	0.1997574E-01

Y(3) CHANGEC-50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8506301E 00	0.2000000E 01
0.6344593E 00	0.1019978E 01
0.2624985E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9889364E 00	0.2000000E 01
0.9593631E 00	0.1019978E 01
0.6643844E-C1	0.1997574E-01

Y(4) CHANGED-50. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8506301E 00	0.2000000E 01
0.6344593E 00	0.1019978E 01
0.2624985E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9889364E 00	0.2000000E 01
0.9593631E 00	0.1019978E 01
0.6643844E-01	0.1997574E-01

Y(5) CHANGED-50.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9544801E 00	0.2000000E 01
0.8521263E 00	0.1019978E 01
0.7743012E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.5829356E 00	0.2000000E 01
0.3420792E 00	0.1019978E 01
0.1180781E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938413E-01	0.1997574E-01

Y(2) CHANGEC-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9043515E 00	0.20000C0E 01
0.7338445E 00	0.1019978E 01
0.1126133E-01	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9995502E 00	0.2000000E 01
0.9982741E 00	0.1019978E 01
0.3158821E 00	0.1997574E-01

Y(3) CHANGED-70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8037362E 00	0.2000000E 01
0.5644149E 00	0.1019978E 01
0.1824840E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9773228E 00	0.2000000E 01
0.9203813E 00	0.1019978E 01
0.4604888E-01	0.1997574E-01

Y(4) CHANGED-70. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.8037362E 00	0.2000000E 01
0.5644149E 00	0.1019978E 01
0.1824840E-02	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9773228E 00	0.2000000E 01
0.9203813E 00	0.1019978E 01
0.4604888E-01	0.1997574E-01

Y(5) CHANGEC-70.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9746677E 00	0.2000000E 01
0.9117042E 00	0.1019978E 01
0.1271988E-01	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

Y(1) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.2487196E 00	0.2000000E 01
0.1291088E 00	0.1019978E 01
0.3943038E-03	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938413E-01	0.1997574E-01

Y(2) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9094996E 00	0.20000C0E 01
0.7446719E 00	0.1019978E 01
0.1916292E-01	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9999503E 00	0.2000000E 01
0.9998074E 00	0.1019978E 01
0.7066784E 00	0.1997574E-01

Y(3) CHANGED-90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.5852519E 00	0.2000000E 01
0.3412527E 00	0.1019978E 01
0.7218951E-03	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.8762150E 00	0.2000000E 01
0.6799299E 00	0.1019978E 01
0.1815669E-01	0.1997574E-01

Y(4) CHANGED-90. PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.5852519E 00	0.2000000E 01
0.3412527E 00	0.1019978E 01
0.7218951E-03	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.8762150E 00	0.2000000E 01
0.6799299E 00	0.1019978E 01
0.1815669E-01	0.1997574E-01

Y(5) CHANGED-90.   PERCENT

TEST MAGNITUDE	TEST FREQUENCY
0.9882569E 00	0.2000000E 01
0.9569549E 00	0.1019978E 01
0.3393016E-01	0.1997574E-01

TEST MAGNITUDE	TEST FREQUENCY
0.9950370E 00	0.2000000E 01
0.9813122E 00	0.1019978E 01
0.9938407E-01	0.1997574E-01

TIME= 15.02 SEC

APPENDIX II THE FACTORING SUBPROGRAM

```
C
C        SUBROUTINE POLRT
C
C        PURPOSE
C           COMPUTES THE REAL AND COMPLEX ROOTS OF A REAL POLYNOMIAL
C
C        USAGE
C           CALL POLRT(XCOF,COF,M,ROOTR,ROOTI,IER)
C
C        DESCRIPTION OF PARAMETERS
C           XCOF -VECTOR OF M+1 COEFFICIENTS OF THE POLYNOMIAL
C                 ORDERED FROM SMALLEST TO LARGEST POWER
C           COF  -WORKING VECTOR OF LENGTH M+1
C           M    -ORDER OF POLYNOMIAL
C           ROOTR-RESULTANT VECTOR OF LENGTH M CONTAINING REAL ROOTS
C                 OF THE POLYNOMIAL
C           ROOTI-RESULTANT VECTOR OF LENGTH M CONTAINING THE
C                 CORRESPONDING IMAGINARY ROOTS OF THE POLYNOMIAL
C           IER  -ERROR CODE WHERE
C              IER=0  NO ERROR
C              IER=1  M LESS THAN ONE
C              IER=2  M GREATER THAN 36
C              IER=3  UNABLE TO DETERMINE ROOT WITH 500 ITERATIONS
C                     ON 5 STARTING VALUES
C              IER=4  HIGH ORDER COEFFICIENT IS ZERO
C
C        REMARKS
C           LIMITED TO 36TH ORDER POLYNOMIAL OR LESS
C           FLOATING POINT OVERFLOW MAY OCCUR FOR HIGH ORDER
C           POLYNOMIALS BUT WILL NOT AFFECT THE ACCURACY OF THE RESULTS.
C
C        METHOD
C           NEWTON-RAPHSON ITERATIVE TECHNIQUE.
C
C

      SUBROUTINE POLRT(XCOF,COF,M,ROOTR,ROOTI,IER)
      DIMENSION XCOF(1),COF(1),ROOTR(1),ROOTI(1)
      DOUBLE PRECISION XO,YO,X,Y,XPR,YPR,UX,UY,V,YT,XT,U,XT2,YT2,SUMSQ,
     1 DX,DY,TEMP,ALPHA
      IFIT=0
      N=M
      IER=0
      IF(XCOF(N+1))10,25.10
   10 IF(N) 15,15,32
   15 IER=1
```

```
20 RETURN
25 IER=4
   GO TO 20
30 IER=2
   GO TO 20
32 IF(N-36) 35,35,30
35 NX=N
   NXX=N+1
   N2=1
   KJ1=N+1
   DO 40 L=1,KJ1
   MT=KJ1-L+1
40 COF(MT)=XCOF(L)
45 XO=.00500101
   YO=0.01000101
   IN=0
50 X=XO
   XO=-10.0*YO
   YO=-10.0*X
   X=XO
   Y=YO
   IN=IN+1
   GO TO 59
55 IFIT=1
   XPR=X
   YPR=Y
59 ICT=0
60 UX=0.0
   UY=0.0
   V=0.0
   YT=0.0
   XT=1.0
   U=COF(N+1)
   IF(U) 65,130,65
65 DO 70 I=1,N
   L=N-I+1
   TEMP=COF(L)
   XT2=X*XT-Y*YT
   YT2=X*YT+Y*XT
   U=U+TEMP*XT2
   V=V+TEMP*YT2
   FI=I
   UX=UX+FI*XT*TEMP
   UY=UY-FI*YT*TEMP
   XT=XT2
70 YT=YT2
   SUMSQ=UX*UX+UY*UY
   IF(SUMSQ) 75,110,75
```

```
 75 DX=(V*UY-U*UX)/SUMSQ
    X=X+DX
    DY=-(U*UY+V*UX)/SUMSQ
    Y=Y+DY
 78 IF(DABS(DY)+DABS(DX)-1.0D-05) 100,80,80
 80 ICT=ICT+1
    IF(ICT-500) 60,85,85
 85 IF(IFIT)100,90,100
 90 IF(IN-5) 50,95,95
 95 IER=3
    GO TO 20
100 DO 105 L=1,NXX
    MT=KJ1-L+1
    TEMP=XCOF(MT)
    XCOF(MT)=COF(L)
105 COF(L)=TEMP
    ITEMP=N
    N=NX
    NX=ITEMP
    IF(IFIT) 120,55,120
110 IF(IFIT) 115,50,115
115 X=XPR
    Y=YPR
120 IFIT=0
122 IF(DABS(Y)-1.0D-4*DABS(X)) 135,125,125
125 ALPHA=X+X
    SUMSQ=X*X+Y*Y
    N=N-2
    GO TO 140
130 X=0.0
    NX=NX-1
    NXX=NXX-1
135 Y=0.0
    SUMSQ=0.0
    ALPHA=X
    N=N-1
140 COF(2)=COF(2)+ALPHA*COF(1)
145 DO 150 L=2,N
150 COF(L+1)=COF(L+1)+ALPHA*COF(L)-SUMSQ*COF(L-1)
155 ROOTI(N2)=Y
    ROOTR(N2)=X
    N2=N2+1
    IF(SUMSQ) 160,165,160
160 Y=-Y
    SUMSQ=0.0
    GO TO 155
165 IF(N) 20,20,45
    END
```

BIBLIOGRAPHY

1. Eldred, R. D., "Test Routines Based on Symbolic Logical Statement," J. ACM, v. 6, pp. 33-36, January 1959.

2. Forbes, R. E., Muller, D. E., and Stieglitz, C. B., "Automatic Fault Diagnosis," AIEE Symp. on Diagnosis of Failures in Switching Circuits, E. Lansing, Mich., May 1961.

3. Seshu, S. and Freeman, D. N., "The Diagnosis of Asynchronous Sequential Switching Systems," IRE Trans. on Electronic Computers, v. Ec-11, pp. 459-465, August 1962.

4. St. Clair, E. Finkel, S. I., and Nelson, R. N., "A Mathematical Technique for Automatic Fault Isolation in Complex System," Vitro Labs, W. Orange, N.J., Final Rept. on Contract AF 33(657)-10113, May 1964.

6. Wofe, J. K. and Dietz, J. H., "A Statistical Theory for Parameter Identification in Physical Systems," J. Franklin Inst., pp. 369-400, November 1962.

7. Seshu, S. and Waxman, R., "Fault Isolation in Conventional Linear Systems--A Feasibility Study," IEEE Trans. on Reliability, v. R-15, No. 1, pp. 11-16, May 1966.

8. Chang, Wen-Tao, "Determination of Network Functions by Topological Method," MSEE Thesis, Naval Postgraduate School, Monterey, California, 1968.

9. Mayada, W. and Seshu, S., "Topological Formulas for Network Functions," Univ. of Illinois, Bul. v. 55, No. 23, Urbana, Ill., November 1957.

10. Weinberg, "Kirchhoff's Third and Fourth Law," IRE Trans. on Circuit Theory, CT-5, March 1958.

11. Chan, S. P., "Introductory Topological Analysis of Electrical Networks," Hold, Rinehart and Winston, 1968.

12. Chan, S. P. and Chan, S. G., "Topological Formula for Digital Computation," Proc. First Annual Princeton Conference on Information Sciences and Systems, pp. 906-912, 1967.

13. Rode, F. and Chan, S. P., "Computer Evaluation of Topological Formulas for Network Analysis," Proc. of the Hawaii International Conference on System Sciences, p. 796, 1968.

14. Maxwell, L. M. and Cline, J. M., "Topological Network Analysis by Algebraic Methods," Proc. IEE (Great Britain) v. 113, No. 8, August 1966.

15. Reza, F., "Some Topological Consideration in Networks Theory," Ct-5, IRE Trans. on Circuit Theory, 1958.

16. Chan, S. P. and Chan, Shu-Gar, "Modification of Topological Formulas," IEEE Trans. on Circuit Theory, CT-15, March 1968.

17. Chen, Wai-Kai, "Generation of Trees and K-trees," Proc. of Third Allerton Conference on Circuit and System Theory, pp. 906-912, October 1965.

18. Mayeda, W. and Seshu, S., "Generation of Trees Without Duplications," IEEE Trans. on Circuit Theory, v. CT-12, No. 12, p. 18, June 1965.

19. Minty, G. J., "A Simple Algorithm for Listing all the Trees of a Graph," IEEE Trans. on Circuit Theory, CT-12, p. 120, March 1965.

20. Myers, B. R. and Auth, Jr., L. V., "The Number and Listing of all Trees in an Arbitrary Graph," Technical Report EE-6511, University of Notre Dame, Indiana, 1965.

21. Percival, W. S., "The Solution of Passive Electrical Networks by Means of Mathematical Trees," Proc. IEEE, v. 100, Part III, pp. 143-150, May 1953.

22. Brownell, R. A., "Growing the Trees of a Graph," Proc. IEEE (Letters), v. 56, pp. 1121-1123, June 1968.

23. Mayeda, W., and others, "Generation of Complete Trees," IEEE Trans. on Circuit Theory, v. CT-15, pp. 101-105, June 1968.

24. Piekarski, M., "Listing all Possible Trees of a Linear Graph," IEEE Trans. on Circuit Theory (Correspondence), v. CT-12, pp. 124-125, March 1965.

25. Bellert, S., "Topological Analysis and Synthesis of Linear Systems," J. Franklin Inst., v. 274, pp. 425-443, December 1962.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor S. G. Chan Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	10
4.	LTJG James Dewey Courville, USN 110 West Evergreen Street Lafayette, Louisiana 70501	1
5.	Commander, Naval Ordnance Systems Command Department of the Navy Washington, D. C. 20360	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Topological Approach to Fault Isolation

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; (June 1969)

5. AUTHOR(S) (First name, middle initial, last name)

James Dewey Courville

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1969	164	25

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

A method is developed for determining by simple external measurements faulty components of passive networks without mutual inductances. A program has been written using topological relationships to calculate the necessary fault isolation reference data. Computation time and storage requirements have been maintained at a minimum.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Network Malfunctions; isolation of						
Fault Isolation						
Topological Formulas						